Study on the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons

Final Report

Prepared by
Amec Foster Wheeler Environment & Infrastructure UK Ltd
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Abstract (Français)

Ce rapport évalue les risques environnementaux, les impacts et les mesures de gestion des risques liés à l'exploration et la production d'hydrocarbures conventionnels en Europe. Il inclut également les procédures et les technologies associées à l'exploration et la production d'hydrocarbures non conventionnels en mer. Cette étude se fonde sur le cycle de vie des activités d'exploration et de production d'hydrocarbures. Chaque aspect (i.e. exploration et production) a été découpé en cinq phases suivant la même division que celle utilisée dans les études précédentes pour la Commission Européenne. Des procédures et technologies spécifiques à chacune de ces cinq phases ont été identifiées.

Pour chaque phase et chaque procédure, les risques et impacts environnementaux ont été évalués sur la base de 8 aspects environnementaux pour les activités en mer (par exemple le bruit) et 10 aspects environnementaux pour les activités à terre. Afin de réaliser cette évaluation, les risques et les impacts de chaque phase ont été analysés et notés en fonction des conséquences et des probabilités associées à ces risques. Cette notation se fonde sur l'analyse de données existantes publiées par l'industrie du pétrole et du gaz (par exemple, des études d'impacts environnementaux) et l'avis des experts participant à cette étude. L'impact des mesures de gestion des risques a également été pris en compte lors de l'analyse des niveaux de risque.

Enfin, les risques et impacts identifiés dans une étude précédente pour la Commission Européenne sur l'exploration et la production d'hydrocarbures non conventionnels à terre ont été comparés aux risques et impacts identifiés au cours de ce projet pour l'exploration et la production d'hydrocarbures conventionnels en mer, afin de déterminer les risques environnementaux liés aux hydrocarbures non conventionnels en mer.

Résumé

Clause de non-responsabilité :

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Objectif du rapport

Ce rapport est le produit final du contrat référencé 070201/2014/693553/ETU/ENV.F.1 et intitulé 'Study on the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons'. Ce rapport présente une synthèse des risques, impacts et des mesures de gestion des risques liés à l'exploration et la production d'hydrocarbures conventionnels en Europe. Il couvre les procédures et technologies associées à l'exploration et la production hydrocarbures conventionnels en mer et à terre. Il traite également des procédures et technologies associées avec l'exploitation de ressources non conventionnelles en gaz situées en mer. (NB. Une étude pour la Commission Européenne publiée en 2014 a considéré l'analyse des risques environnementaux et impacts dus à la production d'hydrocarbures non conventionnels à terre).

Contexte

En janvier 2014, la Commission a adopté une Recommandation relative aux principes minimaux applicables à l'exploration et à la production d'hydrocarbures (tels que le gaz de schiste) par fracturation hydraulique à grands volumes[1]. Amec Foster Wheeler[2] a fourni un soutien technique pour le développement de l'étude d'impact qui accompagnait cette Recommandation. Amec Foster Wheeler a également réalisé une étude deshydrocarbures non conventionnels à terre (gaz et pétrole de formations étanches et méthane de houille).

Ces études précédentes ont examiné les impacts environnementaux et les risques posés spécifiquement par l'exploration et la production d'hydrocarbures non conventionnels à terre, en particulier par fracturation hydraulique. Les procédés et techniques utilisés pour l'exploration et la production d'hydrocarbures conventionnels sur terre et en mer ont été, jusqu' à présent, peu explorés.

Cette étude satisfait les besoins de plusieurs initiatives. Tout d'abord, la Commission est tenue d'examiner l'efficacité de la Recommandation 2014/70/EU, tout en tenant compte des progrès techniques et du besoin de déterminer les risques et impacts de l'exploration et de la production d'hydrocarbures utilisant des techniques autres que la fracturation hydraulique à grands volumes.

De plus, la Communication 'Stratégie européenne pour la sécurité énergétique' identifie l'accroissement de la production d'énergie maximisant le recours aux sources d'énergies indigènes comme une des solutions possibles pour réduire la dépendance de l'Union Européenne à l'égard de certains fournisseurs et combustibles. Cela inclut le besoin d'évaluer le potentiel des hydrocarbures conventionnels et non conventionnels en Europe en tenant compte de l'application des normes environnementales les plus

[1] Recommendation 2014/70/EU
[2] Formerly AMEC

strictes. Cela demande une évaluation des besoins en futures actions dans le domaine de l'extraction du pétrole et du gaz, en particulier pour la gestion des impacts environnementaux et des risques en résultant.

Enfin, ce rapport complète les études précédentes qui se concentraient essentiellement sur les risques dus à l’utilisation de la fracturation hydraulique pour l’exploitation et la production de gaz et pétrole de formations étanches, gaz de schiste et méthane de houille. Ce rapport présente une vue d’ensemble des risques environnementaux, des impacts et des mesures de gestion des risques liés à l’exploration et la production d’hydrocarbures en Europe (ressources conventionnelles à terre et en mer et ressources non conventionnelles en mer).

Objectifs

Les objectifs de cette étude sont de fournir à la Commission les connaissances nécessaires pour évaluer les éventuels besoins d’action pour la gestion des impacts environnementaux et des risques résultant de l’exploration et de la production d’hydrocarbures et considérer la valeur ajoutée d’une telle action à l’échelle européenne.

Ainsi, les objectifs de cette étude sont :

- D’identifier les procédés et les technologies déployés lors de l’exploration et la production d’hydrocarbures (à terre et en mer) et déterminer leurs éventuels risques et leurs impacts environnementaux ;
- D’identifier les mesures de gestion de ces risques et l’évitement ou la réduction de leurs impacts ;
- D’évaluer les impacts environnementaux et les risques des développements en mer pour l’exploration et la production de ressources non conventionnelles ; et
- De déterminer si des mesures complémentaires (ou différentes) sont nécessaires pour gérer les risques résultant des activités d’exploration et de production de ressources non conventionnelles en mer (comparativement aux risques résultant des ressources non conventionnelles à terre) ; et le cas échéant, proposer des mesures appropriées.

Conclusions de l’étude

L’examen des risques et l’évaluation des impacts pour l’exploitation des ressources conventionnelles de pétrole et de gaz ont identifié des différences pour certains aspects environnementaux entre les activités sur terre et les activités en mer. Ces différences affectent la façon dont la maîtrise de ces risques est conçue, en particulier :

- Les milieux marins présentent des défis importants en ce qui concerne le débit et le confinement des substances, en particulier pour le stockage et l’utilisation des substances liquides en mer, comparativement au stockage et à l’utilisation des mêmes substances sur terre. Le mouvement (enlèvement) de produits des installations sur terre vers les installations en mer est également une activité qui présente un niveau de risque plus élevé en comparaison du transport à terre ;
- De la même façon, la propagation du bruit dans les milieux marins et l’exposition des espèces marines, en particulier les cétacés, à une pollution sonore lors de l’installation et du forage des puits requiert des considérations additionnelles comparativement aux aspects environnementaux généralement considérés lorsque ces activités sont menées à terre ;
- Pour les activités menées à terre, l’environnement bâti pose des défis plus importants que pour les activités menées en mer. Cela inclut, entre autres, les

aspects environnementaux associés à la pollution de l'air. Par exemple, les équipements de production d'énergie pour les installations situées à terre sont à proximité des récepteurs et ont un impact plus direct sur l'environnement entourant le site. De plus, l'utilisation du réseau routier pour le transport de biens jusqu'aux installations et au sein de l'installation est une source de problèmes pour l'environnement situé à proximité de ces routes. C'est le cas en particulier de routes reliant les différents puits sur un même site, ou bien celles reliant les puits et les sites de traitement des déchets ou les puits et les points d'abstraction d'eau ; et

- Les autres aspects environnementaux, qui diffèrent à terre des activités conduites en mer, sont associés à l'occupation des sols, la localisation des puits par rapport à l'environnement bâti, et l'utilisation des ressources en eau. Certaines activités, lorsqu'elles sont menées sur terre, posent un risque additionnel pour la santé des humains et des animaux sauvages. C'est le cas par exemple du forage de puits ou de la gestion des eaux de productions qui peuvent potentiellement contaminer les ressources d'eau souterraines et de surface.

Les risques et impacts environnementaux les plus importants sont typiquement liés aux évènements accidentels. Cela est particulièrement notable pour les opérations conduites en mer. L'analyse de la documentation, en particulier celle publiée par l'industrie du pétrole et du gaz, a montré l'existence d'une série de mesures de gestion des risques qui peuvent être utilisées pour minimiser l'impact de ces évènements accidentels.

Malgré cela, un certain nombre d'activités sont considérées comme présentant des risques majeurs et ce, même après avoir pris en compte les mesures de gestion des risques disponibles. Ce résultat reflète également le fait que pour certaines activités, l'adoption de mesures n'est que partielle (par exemple, certaines mesures de gestion de risques ne sont pas appliquées de façon uniforme dans toutes les régions considérées). C'est le cas, par exemple, des émissions de substances polluantes associées à l'évacuation des gaz et leur combustion en torchère.

Un examen des technologies émergentes a été réalisé à la suite de l'identification des risques et impacts. Cet examen a révélé que des technologies émergentes étaient en cours de développement dans 7 domaines thématiques clés qui sont :

- Techniques émergentes de récupération assistée ;
- Robotiques ;
- Technologies sismiques ;
- Unités flottantes de liquéfaction de gaz naturel en mer ;
- Technologies de forage (par exemple tubage enroulé) ;
- Technologies de réduction des émissions (par exemple, combustion à basses émissions) ;et
- Nanotechnologies.

Certaines de ces nouvelles technologies offrent des réductions de risques et d'impacts plus importantes que les technologies conventionnelles. L'utilisation d'unités flottantes de liquéfaction de gaz naturel en mer, par exemple, réduit le besoin en installations terrestres pour le traitement de ce gaz, et par extension, réduit l'impact de ces installations tout au long de leur cycle de vie (occupation des sols, proximité des récepteurs sensibles aux émissions d'hydrocarbures). Pour d'autres, les bénéfices étaient moins évidents, c'est le cas par exemple des nanotechnologies pour lesquelles plus de recherches sont nécessaires pour en comprendre les risques environnementaux.

Après avoir analysé les risques et les impacts associés aux ressources conventionnelles en pétrole et en gaz, ce projet a comparé les risques et impacts associés aux techniques de stimulation de puits (y compris la fracturation hydraulique à faible volume) avec ceux associés aux techniques de récupération assistée utilisées pour les ressources conventionnelles à terre. La comparaison a également inclus la fracturation hydraulique à grands volumes utilisée pour les ressources non conventionnelles. Il est prévu que l'utilisation de techniques de stimulation des puits et de récupération assistée augmente dans les années à venir. Cette augmentation irait de pair avec des progrès en recherche et développement et une hausse des prix des hydrocarbures.

Sur la base des sources analysées, y compris des références spécialisées sur la fracturation hydraulique pour les ressources conventionnelles et non conventionnelles, il semblerait que la différence principale entre la fracturation hydraulique utilisée pour l'extraction de ressources conventionnelles et celle utilisée pour l'extraction de ressources non conventionnelles est le volume de fluide injecté (et par conséquent le volume de refoulement). Les risques et les impacts suivants sont déterminés en fonction de l'échelle et du volume des activités de fracturation:

- Occupation des sols : l'augmentation du volume de fracturation hydraulique mène à l'augmentation de l'espace nécessaire (plus de liquide de fracturation et de refoulement et plus d'équipements) ;
- Circulation : l'augmentation des quantités de liquide de fracturation (et par conséquent de refoulement) et des équipements nécessaires mène à l'augmentation des trajets et de la circulation ;
- Contamination des eaux de surface : de plus grands volumes de fracturation accroissent les conséquences potentielles de défaillance de confinement ; et
- Epuisement des ressources en eau : de plus grands volumes de fracturation mènent à plus de stress hydrique pour les ressources en eau locales.

De plus, les risques et les impacts associés avec les techniques de récupération assistée déployées à terre (par exemple inondation, injection de polymères, de vapeur ou de gaz miscible) ont été comparés avec ceux associés aux techniques de fracturation hydraulique à grand volume dans le cadre de l'extraction des ressources non conventionnelles. Des différences et des similitudes entre les deux activités ont été identifiées, et sont présentées dans ce rapport (Section 8), elles incluent notamment :

- L'injection de substances peut générer des risques de magnitude semblable à ceux présentés par la fracturation hydraulique. Cela est dû à la grande quantité de substances chimiques conservée et utilisée en surface.
- Les impacts visuels des installations ayant recours à l'injection de substance et d'eau peuvent être moindres que les impacts visuels des puits ayant recours à la fracturation hydraulique à grand volume. En effet, dans ce cas, il y a souvent un besoin extensif d'occupation des sols dus aux nombreux puits (par exemple lors de l'exploitation de gaz de schiste). Par conséquent, ces impacts visuels sont plus comparables à ceux observés pour les puits conventionnels.
- Par ailleurs, les risques associés aux techniques de récupération assistée sont généralement considérés comme comparables à ceux présentés par la fracturation hydraulique, bien que la nature de ces risques puisse clairement varier (par exemple les types de substances utilisées ou l'utilisation d'équipement en surface, etc.). Cependant, il est important de noter qu'une comparaison exacte n'est pas possible due aux différences entre les activités considérées.

Enfin, un des aspects de ce projet était d'évaluer les défis associés aux ressources non conventionnelles de pétrole et de gaz situées en mer. Les études précédentes réalisées pour la Commission Européenne ont considéré les risques environnementaux associés à l'extraction des ressources non conventionnelles à terre, c'est-à-dire le gaz et pétrole de formations étanches, gaz de schiste et méthane de houille.

Dans un premier temps, l'examen de l'exploitation et production de ressources non conventionnelles en mer a débuté par l'analyse des activités supplémentaires dues à la nature non conventionnelle des ressources. Dans un second temps, une analyse a été effectuée pour comprendre dans quelle mesure les dispositifs en place pour les ressources conventionnelles en mer seraient applicables et adaptés à la gestion de nouveaux risques et des impacts associés aux ressources non conventionnelles.

Tout d'abord, l'analyse a montré que pour les activités en mer, le gaz de formations étanches est la ressource non conventionnelle actuellement exploitée, tandis que des concessions pour l'exploration de gaz de schiste en mer ont été octroyées mais aucune activité n'a pour l'instant été identifiée. L'exploration et la production de pétrole contenu dans des formations étanches en mer sont jugées non rentables et l'extraction du méthane de houille en mer semble être non viable à cause des procédés associés nécessaire.

L'analyse des procédés et techniques pour l'extraction de gaz de formation étanche a relevé un certain nombre de risques et d'impacts qui s'ajoutent à ceux associés aux ressources conventionnelles. L'application de ces risques et impacts aux milieux maritimes a été évaluée. Il a été conclu que les risques et impacts environnementaux suivants sont à la fois pertinents et supplémentaires à ceux identifiés pour les ressources conventionnelles en mer pour les catégories suivantes :

- Rejets à la mer (par exemple dus à l'augmentation du volume de refoulement)
- Epuisement des ressources en eau (dans le cas où de l'eau douce serait transportée en mer pour la fracturation)
- Activité sismique induite (dans le cas où la fracturation hydraulique / la récupération assistée ne ferait pas partie d'une activité d'extraction de ressources conventionnelles)

En outre, il a été impossible de décider fermement (du à des preuves contradictoires) si les risques présentés par les puits conventionnels et les puits non conventionnels différaient pour les aspects suivants :

- Décharge maritime (perte d'intégrité à la suite des phases de fermeture et d'abandon du puits)
- Emissions atmosphériques (dues aux émissions fugitives de méthane émises pendant la production).

Ces aspects mériteraient plus ample recherche.

Les risques et impacts associés aux aspects environnementaux de ces catégories identifiées comme pertinentes ont ensuite été comparés aux mesures de gestion des risques qui sont actuellement appliquées par l'industrie aux activités conventionnelles à terre et en mer. Les conclusions de cette comparaison, fondées sur le jugement des experts et étayées par les données publiées par l'industrie, sont que les mesures disponibles et susceptibles d'être appliquées aux opérations en mer sont considérées adaptées et aptes à réduire les risques, identifiés comme associés à l'extraction de ressources non conventionnelles en mer, à un niveau comparable aux risques associés à l'extraction de ressources conventionnelles en mer. Cette conclusion ne concerne pas ces aspects pour lesquels il a été impossible d'identifier des preuves convaincantes afin de savoir si les risques étaient plus importants pour les activités non conventionnelles que pour les activités conventionnelles, en particulier pour les émissions fugitives de méthane et l'intégrité à long-terme du puits.

Enfin, il est important de noter que les impacts et risques cumulés n'ont pas été considérés dans ce rapport. De plus, d'autres facteurs, géographique entre autres, influencent les conclusions de ce rapport, par exemple des mers plus profondes ou aux courants plus forts, des conditions venteuses plus importantes ou des températures plus basses. Tous ces facteurs peuvent augmenter la probabilité d'impacts et leurs conséquences.

Abstract (English)

This report assesses the environmental risks, impacts and risk management measures associated with the conventional exploration and production of hydrocarbons within Europe. It also covers processes and technologies associated with offshore unconventional activities. The study used a lifecycle approach to break down exploration and production of hydrocarbons into five stages following a similar approach used for previous studies for the European Commission. Sub-stages and processes were then identified for each life-cycle stage for both offshore and onshore.

For each process and sub-stage the environmental risks were assessed based on 8 environmental aspects (e.g. noise) for offshore and 10 for onshore. To conduct this assessment the risks and impacts of each aspect were reviewed against a risk rating system, based on consequence and likelihood. The assessment was conducted using a combination of data gathered from the oil and gas industry, including environmental impact assessments/statements, and expert judgement. The impacts of management measures on risks were also assessed.

Finally, the risks and impacts identified for onshore unconventional exploration and production from a preceding study were compared to the risks and impacts of offshore conventional exploration and production in this study to determine the environmental risks of offshore unconventionals at sea.

Executive summary

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Purpose of this report

This report concerns a 'study on the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons', contract 070201/2014/693553/ETU/ENV.F.1. The report presents an overview of the risks, impacts and risk management measures associated with processes and technologies used in the production of hydrocarbons within Europe. This covers the processes and technologies associated with conventional oil and gas found both onshore and offshore. It also covers those processes and technologies associated with unconventional gas offshore. (A review of environmental risks and impacts for production of unconventional hydrocarbons onshore was completed in a previous European Commission study.)

Context

In January 2014, the Commission adopted a Recommendation laying down minimum principles for the exploration and production of onshore hydrocarbons (such as shale gas) using high-volume hydraulic fracturing. Amec Foster Wheeler[3] provided technical support to the development of the evidence base for the Impact Assessment of policy options that led to the Recommendation. Amec Foster Wheeler extended the technical support through a further study regarding other onshore unconventional hydrocarbons (tight gas, tight oil and coal bed methane).

The focus of the Recommendation and Commission studies to date has been on the environmental impacts and risks specific to onshore unconventional hydrocarbon exploration and production, particularly those using hydraulic fracturing. Processes or techniques commonly used for onshore and offshore conventional hydrocarbons, and offshore unconventional hydrocarbons were not investigated.

There are a number of linked drivers for this study. Firstly, Recommendation 2014/70/EU calls on the Commission to take into account technical progress and the need to address risks and impacts of the exploration and production of hydrocarbons using techniques other than high-volume hydraulic fracturing, as part of a review of the effectiveness of the Recommendation.

Secondly, the Communication on a European Energy Security Strategy outlines the possible further development of hydrocarbons from conventional and unconventional sources in the EU. This requires an assessment as to whether further policy action in the field of oil and gas extraction is needed, in particular with regard to the management of related environmental impacts and risks.

This study complements earlier studies[4] that focused on the risks related to hydraulic fracturing used for the onshore exploration and production of CBM, tight gas, tight oil and shale gas. The study provides an overview of environmental risks and impacts

[3] Formerly AMEC
[4] http://ec.europa.eu/environment/integration/energy/uff_studies_en.htm

and associated risk management measures for the wider hydrocarbon sector (i.e. onshore conventional, offshore conventional and offshore unconventional).

Objectives

The objective of this study was to help provide the Commission with the necessary knowledge basis to assess the need for possible further policy action on the management of environmental impacts and risks resulting from the exploration and production of hydrocarbons, and the EU added value thereof.

In doing so, the purpose of this study is to:

- Identify processes and technologies used for the conventional exploration and production of hydrocarbons (onshore and offshore) and determine their potential risks and environmental impacts;
- Identify measures for the management of these risks and the avoidance or reduction of impacts;
- Assess environmental impacts and risks of the offshore development of unconventional fossil fuels; and
- Examine the extent to which additional or different risk management measures are needed to address risks of offshore unconventional hydrocarbon exploration and production activities (as compared to onshore unconventional hydrocarbon development); and if so, propose relevant measures.

Study conclusions

The review of risks and impacts assessment for conventional oil and gas highlighted differences for certain environmental aspects between onshore and offshore, which affected the focus of how risks were managed, in particular:

- The marine environment presents bigger challenges around the flow and containment of substances, particularly the storage and use of liquid substances at sea, compared to storage and use of such substances onshore. The movement (e.g. offtake) of goods from onshore to offshore installations is also a key activity which may present higher levels of risk, compared to onshore transportation;
- Equally the issue of 'noise' within the marine environment and exposure of marine life, particularly cetaceans, to noise during the installation and drilling of wells poses a different kind of challenge to manage compared to the equivalent environmental aspect for onshore operations;
- For the onshore operations the issues of 'built environment' pose greater challenges than seen for offshore. This includes for example the environmental aspects associated with air pollution from e.g. energy generating equipment with onshore sources being generally closer to receptors and hence having more direct impact upon the surrounding environment. Equally the use of road transport to move goods to and from site, due to the close proximity to people, poses issues for the immediate environment around the well site and between the well site and waste facilities or water abstraction points; and
- Other environmental aspects onshore that differ in nature to the offshore activities relate to 'land-take' for placing of well sites in relation to the built environment, and the use and management of water resources. There are also aspects of onshore activities, such as well drilling or the management of produced water, that carry a risk of contaminating groundwater and surface water, which impacts humans and wildlife.

The biggest environmental risks and impacts typically relate to accidental events, especially those for offshore oil and gas. Based on the documents reviewed the oil and gas industry has a wide range of risk management measures available to aid in avoiding or mitigating the magnitude of such events.

However in completing the risk and impact assessment, there were still a number of activities with relatively high remaining risk after management measures had been taken into consideration, which also partially reflects the uptake of measures (e.g. where key risk management measures may not be applied consistently across all regions). These activities are for instance pollutant emissions associated with gas flaring and venting.

As a follow on task from the risk and impact assessment, a review of emerging technologies was carried out. The review for emerging technologies identified developments relating to seven key themes which cover:

- Emerging enhanced recovery techniques;
- Robotics;
- Seismic technologies;
- Floating Liquid Natural Gas (LNG) installations;
- Drilling technologies – such as coiled tubing;
- Emission reductions technologies – such as Dry Low Emissions (DLE); and
- Nanotechnologies.

Some of the new technologies identified had the potential to further reduce the risk and impact from conventional operations. For example the use of floating LNG installations to carry-out the processing of gas at sea reduces the need for onshore processing facilities and potential impacts for onshore throughout the life cycle (e.g. land take and proximity of sensitive receptors to sources of hydrocarbon release). Other emerging technologies examined, such as nanotechnologies, would require further research in order to ascertain their full impact on environmental risks.

Following the completion of the review for the risks and impacts associated with conventional oil and gas, the project also compared the risks and impacts of employing well stimulation (including low volume hydraulic fracturing) and enhanced recovery techniques in conventional onshore wells, as compared to high-volume hydraulic fracturing (HF) used in unconventional. It is expected that the use of well stimulation and enhanced recovery techniques will increase in the future, as R&D progresses and hydrocarbon prices rise.

Based on the review, including information on fracturing in conventional and unconventional wells, it was determined that, in broad terms, the volume of fluid injected (and hence volume of flowback) was the only variable that changed significantly between hydraulic fracturing used in conventional and unconventional extractions. Risks and impacts related to the following aspects were determined to scale based on the size of the fracturing operation.

- Land take: additional fracturing fluid, flow back and equipment requires more space with greater fluid volumes;
- Traffic: additional fracturing fluid, flow back and equipment has increased transport requirements;
- Surface water contamination: high volumes increase the potential consequences of containment failure; and
- Water resource depletion: high volumes of water result in greater stress on local water resources.

Additionally, the risks and impacts associated with onshore enhanced recovery techniques (water flooding, polymer injection, steam injection and miscible gas injection) were compared to HF in unconventional wells. A number of differences and similarities were identified, as set out in this report (section 8), such as:

- Substance injection may cause risks of a potentially similar magnitude to hydraulic fracturing, due to the large quantities of chemicals stored and used above ground;
- Visual impacts of installations using substance injection and water flooding may be less than for wells involving HVHF, where there are often significant land-use requirements for multiple well pads (e.g. in the case of shale gas plays). They may therefore be more readily comparable to conventional wells; and
- Otherwise the risks associated with enhanced recovery techniques are broadly considered to be of a comparable scale to those associated with hydraulic fracturing, although the nature of those risks may clearly vary (e.g. types of substances used, above-ground equipment, etc.). However, it should be borne in mind that a precise comparison is not possible, due to the differences in activities involved.

Finally, the project also assessed the issue of unconventional offshore oil and gas. Previous studies completed on behalf of the Commission have looked at the issue of environmental risk for onshore unconventional oil and gas, which is assumed to encompass tight gas, tight oil and coal bed methane.

The review for offshore unconventionals initially assessed what additional activities/life-cycle stages might need to be included within the offshore processes compared to conventional operations, and specifically which environmental aspects might be affected. Then as a second step the review assessed whether the existing measures in use for conventional offshore would be appropriate to manage the new risks and impacts identified with unconventional hydrocarbons.

The first stage of this process identified that for offshore activities, the current activity in the EU relates to tight gas production, while licenses are in place for shale gas exploration but no activities have yet been reported[5]. The exploration and production of tight oil was deemed non-economical for offshore environments, while the related processes to recover coal bed methane mean that offshore production is likely to be non-viable. The review for tight gas[6] identified a number of risks and impacts additional to conventional oil and gas, which were then assessed for relevance to the offshore environment. Following this review the following environmental aspects were identified as being relevant and additional to those for conventional offshore processes:

- Discharges to sea (e.g. due to increased flow back volumes);
- Water resource depletion (only if fresh water for fracturing is shipped from shore); and
- Induced seismicity (only if hydraulic fracturing/enhanced recovery is not applied as part of conventional extraction).

In addition, a judgement could not be made (due to conflicting evidence) as to whether risks differed for unconventional wells compared to conventional wells, for the following aspects:

[5] IOGP, September 2016

[6] The review focused on experience to date mainly with tight gas extracted offshore. Whereas there may be permits allowing shale gas extraction offshore, to date there have been no wells targeting offshore shale gas being drilled in Europe.

- Discharges to sea (due to long-term loss of well integrity following closure and abandonment); and
- Releases to air (due to fugitive methane emissions during production).

The above aspects would therefore merit further research and investigation.

The risks and impacts associated with the environmental aspects that were identified as being relevant and additional to those for conventional onshore processes were then compared against the current management measures used by the conventional offshore oil and gas industry to assess whether they would be suitable to also manage these additional risks and impacts. Based on the conclusion of this review, which was conducted using expert judgement, and where possible substantiated with publicly available literature and industry data[7], the measures that are already available and likely to be applied offshore are considered to be capable of reducing the identified risks of unconventional hydrocarbon extraction offshore to a comparable level to that for offshore conventional hydrocarbon extraction activities. This conclusion excludes those aspects for which there is conflicting evidence as to whether risks are increased for unconventional activities as compared to conventional, specifically fugitive methane leaks and long-term well integrity failure.

Finally, it is important to note that cumulative impacts and risks have not been considered in this report. In addition, other factors may influence the conclusions of this report that are not considered, for example roughers seas or stronger currents, windy conditions or lower temperatures. All these factors can increase the likelihood and consequence of the assigned impacts and consequences.

[7] The available information sources varied across the issues examined within this study. A combination of published, peer-reviewed literature, internal knowledge and expert judgement and industry data were used. The extent of independent verification of non-peer-reviewed data is generally not known. It should therefore be borne in mind that the evidence base for different issues will inevitable vary.

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1. Introduction

1.1 Purpose of this report

This report concerns a 'study on the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons', contract 070201/2014/693553/ETU/ENV.F.1. The report presents an overview of the risks, impacts and risk management measures associated with processes and technologies used in the production of hydrocarbons within Europe. This definition covers the processes and technologies associated with conventional oil and gas found both onshore and offshore. It also covers those processes and technologies associated with unconventional oil and gas offshore. The review of environmental risks and impacts for production of unconventional hydrocarbons onshore was covered by a previous study on behalf of the European Commission.

1.2 Context

In January 2014, the Commission adopted a Recommendation laying down minimum principles for the exploration and production of onshore hydrocarbons (such as shale gas) using high-volume hydraulic fracturing. The Recommendation focussed on:

- Early planning and evaluating possible cumulative effects before granting licences;
- Assessing environmental impacts and risks;
- Ensuring that the integrity of the well is best practice;
- Checking the quality of the local water, air and soil before operations start (baseline establishment), to enable the monitoring of any changes and deal with emerging risks;
- Controlling air emissions, including greenhouse gas emissions;
- Informing the public about chemicals used in individual wells; and
- Ensuring that operators apply best practices throughout the project.

Amec Foster Wheeler[8] provided technical support to the development of the evidence base for the Impact Assessment of policy options that led to the Recommendation. Work completed by AEA and Milieu (AEA, 2012) for the Commission provided further evidence. Amec Foster Wheeler's supporting work focused on onshore development of shale gas resources. Amec Foster Wheeler (2015a) extended this technical support through a further study regarding other onshore unconventional hydrocarbons (tight gas, tight oil and coal bed methane).

The focus of the work to date has been on the environmental impacts and risks specific to onshore unconventional hydrocarbon exploration and production using hydraulic fracturing. Processes or techniques that were commonly used for onshore conventional and offshore unconventional hydrocarbons were not investigated.

There are therefore a number of linked drivers for this study. Firstly, Recommendation 2014/70/EU calls on the Commission to take into account technical progress and the need to address risks and impacts of the exploration and production of hydrocarbons using techniques other than high-volume hydraulic fracturing, as part of a review of the effectiveness of the Recommendation.

Secondly, the Communication on a European Energy Security Strategy outlines the possible further development of hydrocarbons from conventional and unconventional sources in the EU. This requires an assessment as to whether further policy action for

[8] Formerly AMEC.

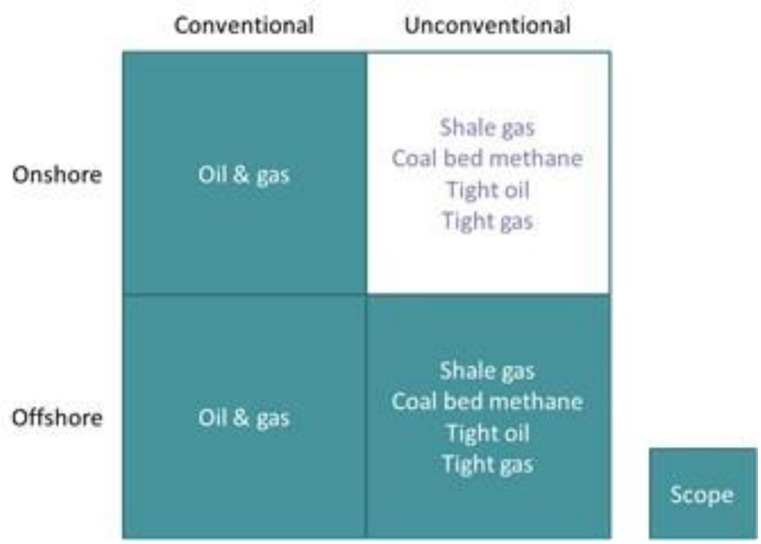
the sector is needed, in particular with regard to the management of related environmental impacts and risks.

This study complements earlier studies carried out by Amec Foster Wheeler that focused on the risks related to the onshore exploration and production of CBM, tight gas, tight oil and shale gas. These studies did not focus on:

- Identification and assessment of risks and impacts resulting from technologies and processes applied by the sector in general (i.e. oil and gas activities considered commonly as 'conventional'); and
- Specific impacts and risks resulting from offshore activities, be it for the production of hydrocarbons from conventional or unconventional sources.

Therefore, this study provides an overview of environmental risks and impacts and associated risk management measures for the hydrocarbon sector (i.e. onshore conventional, offshore conventional and offshore unconventional). Figure 1.1 provides an overview of how the scope for the current and previous projects define the area of study.

Figure 1.1: Scope of current study



1.3 Objectives

The objective of this study was to provide the Commission with the necessary knowledge basis to assess the need for possible further policy action on the management of environmental impacts and risks resulting from the exploration and production of hydrocarbons, and the EU added value thereof.

In doing so, the purpose of this study was to:

- Identify processes and technologies used for the conventional exploration and production of hydrocarbons (onshore and offshore) and determine their potential risks and environmental impacts;
- Identify measures for the management of these risks and the avoidance or reduction of impacts;
- Compare the risks and impacts resulting from processes within unconventional exploration and production offshore (particularly the use of high volume hydraulic fracturing) against those processes used in exploration and production for

conventional (both onshore and offshore) and unconventional onshore wells (with mitigation measures in place);

- Assess environmental impacts and risks of the offshore development of unconventional fossil fuels; and
- Examine the extent to which additional or different risk management measures are needed to address risks of offshore unconventional hydrocarbon exploration and production activities (as compared to onshore unconventional hydrocarbon development); and if so, propose relevant measures.

1.4 Scope and boundary of the study

1.4.1 Scope detail

The project scope includes the following elements:

- Characterisation of processes and technologies used currently within the EU for production of hydrocarbons. This includes, wherever possible, the further detail of regional specific approaches that may relate to differing aspects of production;
- Use of industry documentation to detail work completed by the oil and gas sector in the identification and management or risks. This included details on what measures have been adopted by the oil and gas sector as standard practice for risk management;
- Development of ranked risks making use of the risk matrix used in the previous supporting studies;
- Comparison of impacts and risks resulting from well stimulation, including hydraulic fracturing and enhanced recovery techniques between conventional and unconventional wells; and
- Comparison of offshore unconventional fossil fuel (UFF) activities and technologies against those identified for onshore UFF and offshore conventional fossil fuels (CFF). Offshore UFF is a developing industry with only limited information available. This report outlines the current state of knowledge for these activities and associated risks.

1.4.2 Boundaries

The project objectives are focussed on those environmental risks and impacts associated with the exploration and production of hydrocarbons from onshore and offshore CFF and offshore UFF. The scope of the project has been limited to these aspects only and does not cover any 'downstream' activities such as processing of crude oil and gas.

Figure 1.2 and Figure 1.3 illustrate specifically those processes and technologies covered within the scope of the current project. All activities that occur outside of the red dotted lines are excluded from the scope of this project. Additionally, the following aspects are not within the scope of this study:

- Environmental impacts and risks resulting from the onshore development of unconventional hydrocarbons; and
- Issues related to safety of work and workers' health.

Figure 1.2: Scope of project boundary – offshore production

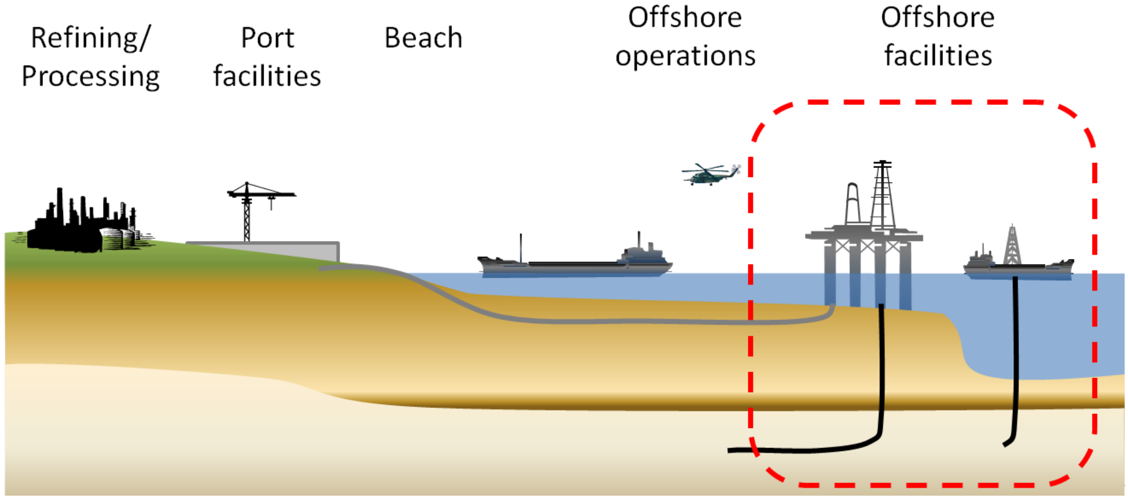
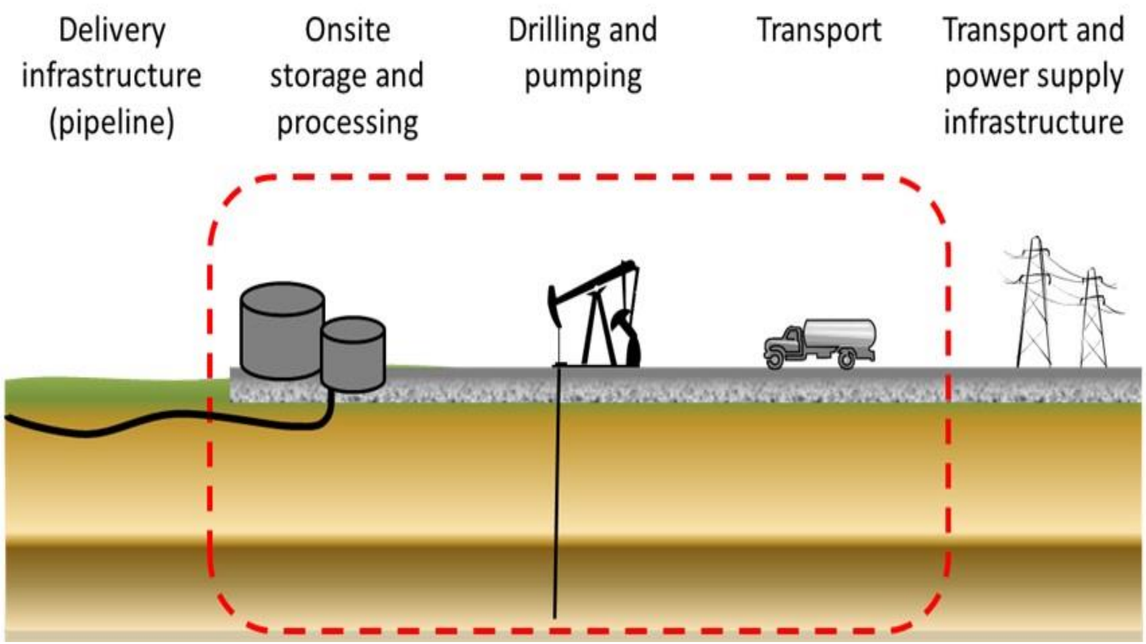


Figure 1.3: Scope of project boundary – onshore production



1.4.3 Study limitations

This study has the following limitations:

- This study represents the current ongoing activities within the oil and gas sector for exploration and production of hydrocarbons at EU level. Given the complexity of the industry, effort has been made to ensure the information provided covers as detailed an overview of the processes and technologies used as possible. Where specialist or bespoke technologies are used for limited application reference has been made to attempt to document these details also. However it is intended that this report should be reflective of the industry as a whole, so core mainstream activities have been given preference for identification of risks and impacts. It is a highly diverse industry, and the report cannot feasibly reflect the full range of technologies, geographical locations and environmental issues for every installation. It is for instance acknowledged that deeper or rougher seas, more windy conditions or colder temperatures may increase the likelihood of impacts;

- It should be borne in mind that there is currently limited exploration and production of offshore UFF involving the use of hydraulic fracturing in the EU so work has had to take into account limited existing and potential future developments;
- The focus of the study elements relating to UFF was on water-based fracturing. Non-water-based and new technologies would require a separate assessment of risks and technical measures if these were to be considered as part of a risk management framework. The previous study regarding onshore UFF also adopted this approach and therefore in adopting the same limitation continuity is also maintained;
- The analysis of risks and management measures has relied on a combination of available published, peer-reviewed literature, internal knowledge and expert judgement and industry data were used. The extent of independent verification of non-peer-reviewed data is generally not known[9] and in some cases lacking in specific academic literature on certain Oil and Gas activities. It should therefore be borne in mind that the evidence base for different issues will inevitable vary and the outputs should therefore be viewed as indicative and not definitive or comprehensive; and
- Cumulative impacts and risks could not be examined in this study because it is not possible to provide an accurate evaluation covering oil and gas fields in general. There are a variety of factors that affect the impacts for any given oil or gas field which cannot be covered in this evaluation alone. It should therefore be noted that the cumulative impacts of several installations in close proximity may vary. Furthermore, other factors such as deeper or rougher seas, wind conditions, cold temperatures, geology, etc., may all increase the likelihood of impacts.

1.5 Summary of the project process

A stepwise process was followed entailing:

(i) Definition of life-cycle stages for Conventional Fossil Fuels (CFF), largely based on the preceding work by Amec Foster Wheeler, AEA and Milieu;

(ii) Categorisation of processes and technologies that take place within each life-cycle stage for CFF, which may vary for onshore/offshore;

(iii) Identification of risks, impacts and measures in place to manage the processes and technologies identified in the previous stage;

(iv) Based on the information gathered, review of technological developments and trends within conventional hydrocarbon;

(v) Comparison of the risks and impacts of well stimulation/enhanced recovery techniques used in conventional and high-volume hydraulic fracturing used in unconventional wells, with risk management measures in place (Table 8.1); and

[9] Referenced information (excluding academic literature) that are published on widely used online portals e.g. OGP/IOGP are assumed to be independently reviewed, but the nature and extent of such reviews is not known for all sources.

(vi) Comparison of the risks, impacts and measures associated with offshore unconventional fossil fuels (UFF) against those risks, impacts and measures identified for onshore UFF and offshore CFF.

1.6 Report structure

The report is presented in the following sections:

- **Section 1: Introduction.** An introduction to the report which defines the purpose and objectives of the report, the context of the study;
- **Section 2: Definition of the scope and activities associated with CFF.** This section provides an overview of the life-cycle stages for onshore and offshore CFF, typical processes and technologies used and boundaries for successive sections;
- **Section 3: Technological development and trends.** A summary of technological trends and emerging technologies identified in the oil and gas sector, which may affect environmental risks in the future;
- **Section 4: Approach to risk and impacts**. This section details the approach used in sections 5 and 6 to determine and categorise risks and impacts associated with onshore and offshore CFF exploration and production;
- **Section 5**: **Risks and impacts of onshore activities.** This section details the processes and technologies within the project scope based on a life cycle stage-by-stage approach. A summary of identified environmental risks and impacts is provided at the end of the section for onshore and offshore respectively;
- **Section 6**: **Risks and impacts of offshore activities.** This is the same as section 5, but for offshore activities;
- **Section 7: Measures.** A review of measures developed for CFF is presented, together with an assessment of whether or not the measures are likely to be proportionate to the risks presented;
- **Section 8: Risk comparison of hydraulic fracturing and enhanced recovery techniques in conventional and unconventional onshore wells.** This section examines the risks identified for the use of low volume fracturing and enhanced recovery techniques in onshore conventional activities and compares them to those identified for high-volume hydraulic fracturing in unconventional wells in previous studies;
- **Section 9: Environmental risks and impacts for offshore UFF**. This section provides a comparative analysis of the risks, impacts and measures in place for onshore UFF versus offshore UFF to assess whether any gaps exist. Where gaps are identified discussion includes whether the measures in place for offshore conventional and onshore unconventional operations would be sufficient to provide appropriate risk management;
- **Section 10: Conclusions.** Conclusions of the study are summarised and presented;
- **Section 11: References.** References used in the study are listed;
- **Appendix A:** The full risk management matrix for onshore activities is presented;
- **Appendix B:** The full risk management matrix for offshore activities is presented; and
- **Appendix C:** A description of the conventions that apply in different regions of EU seas.

2. Definition and scope of activities for conventional offshore and onshore activities

2.1 Introduction

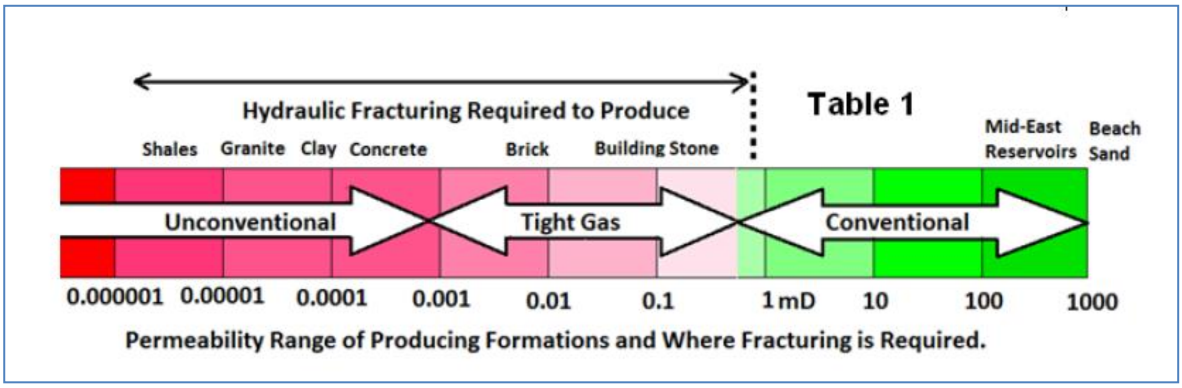
The objective of this section is to discuss the criteria that have been used to derive technical definitions of what constitutes CFF and UFF. In addition this section provides more detailed discussion on the life-cycle stages for onshore and offshore CFF, where differences exist and the processes and technologies employed in the exploration and production of hydrocarbons. In providing this text consideration has been given to the ongoing activities occurring within the European Union. In developing an understanding of the necessary processes and technologies that underpin each life-cycle stage it has been necessary to strike a balance in providing a detailed overview of the industry practice against the full range of potential technologies available. In cases where limited applications have been used for bespoke sites, expert judgement has been used as to whether the potential risks posed are sufficiently significant to be included within the standard definitions for oil and gas exploration and production.

2.2 Categorisation of conventional and unconventional fossil fuels

A universally recognised distinction between conventional fossil fuels (CFF) and UFF is not available. What is considered to be UFF may vary over time depending on various aspects (e.g. resource characteristics, technologies, scale, frequency and duration of production from the resource). The term 'unconventional' may be used to identify the use of previously rarely-deployed techniques; however, such techniques may also be applied to CFF resources and so may no longer represent 'unconventional' techniques over time. An alternative definition refers to hydrocarbons present in the source rock in which the resource was originally formed. Such a definition includes shale gas and CBM but excludes tight oil and tight gas where hydrocarbons have migrated from a source rock to a reservoir.

A number of potential criteria are possible to differentiate between CFF and UFF. Firstly, the permeability of the reservoir rock may be considered, as illustrated in Figure 2.1 Shale gas, tight oil and tight gas are found in formations with lower permeability than CFF. However, the permeability of CBM is more variable and therefore cannot be readily distinguished from CFF on this basis. Secondly, the geological environment in which CFF and UFF are found may be used to differentiate as CFF are typically found in discrete accumulations (e.g. where a cap rock overlies and contains a reservoir) whereas UFF may be found in much more extensive bodies with more gradational boundaries. Thirdly, the techniques used to exploit CFF versus UFF and in particular the scale of drilling are different, with the extensive use of horizontal wells, and stimulation being required at the production stage for UFF. Fourthly, shale gas, tight gas and tight oil resources may be grouped as they share characteristics including depth, scale of operations at a well pad, the use of multi-well pads (and associated land take) and a requirement for the use of hydraulic fracturing to enable production. CBM resources form a separate group due to the shallower depth, reduced scale of operations, the use of hydraulic fracturing which is not always required and the smaller volume of fracturing fluid used for fracturing. In addition, CBM requires groundwater pumping whereas the other forms of UFF do not. Finally, whilst stimulation of reservoirs by hydraulic fracturing can be used in both CFF and UFF, there are differences in pressure and the volume of water used in the process.

Figure 2.1: Permeability Scale for Distinguishing Between CFF and UFF



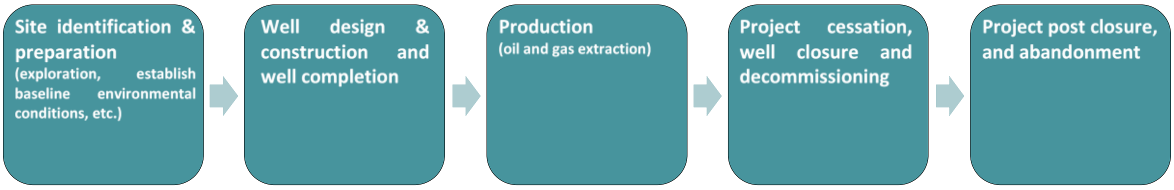
2.3 Lifecycle stages

The previous studies completed on behalf of the Commission Services have identified a number of stages across exploration and production which can be defined across the well and field lifecycle. In particular the AEA (2012) study on hydraulic fracturing in shale summarised six key stages as:

- **Stage 1:** Site identification and preparation. Site preparation activities consist primarily of clearing and levelling an area of adequate size and preparing the surface to support movement of heavy equipment plus design and construction of access routes;
- **Stage 2:** Well design; drilling; casing; cementing; perforation. The first drilling stage is to drill, case, and cement the conductor hole at the ground surface. A vertical pipe is set into the hole and grouted into place. The second drilling stage is to drill the remainder of the vertical hole. Surface and intermediate casings are constructed, cemented and horizontal bores drilled. The pipework and cement is then perforated, and the wellhead constructed;
- **Stage 3:** Technical hydraulic fracturing. Water with proppant (typically sand) and chemicals is pumped into the well at high pressure;
- **Stage 4:** Well completion and management of wastewater. During the well completion phase, operators need to process flowback and produced water;
- **Stage 5:** Production. Gas is extracted and put into supply. Produced water is separated from the gas and disposed of; secondary and enhanced recovery techniques can be employed; and
- **Stage 6:** Decommissioning/abandonment.

The subsequent studies by Amec Foster Wheeler to look at all unconventional fossil fuels recognised that high volume hydraulic fracturing acted as an additional life-cycle stage compared to the conventional production of oil and gas. In conventional wells hydraulic fracturing at lower volumes and enhanced recovery processes can be practised. In the current study, a five life-cycle stage description is used, to encompass both UFF and CFF. Hydraulic fracturing and enhanced recovery techniques in this case falls under the ‘Production’ lifecycle stage. These five life-cycle stages are detailed within Figure 2.2.

Figure 2.2: Lifecycle stages[10]



2.4 Processes and technologies

2.4.1 Onshore

2.4.1.1 Overview

This section presents key information for onshore conventional oil and gas exploration and production. Main process and technologies are described at a summary level within Table 2.1[11]. The initial phase in oil and gas operations includes generation of a prospect or play or both, and the drilling of exploration wells. Well testing, development and production phases follow successful exploration. The list of stages, sub-stages and processes/technologies is outlined below, providing an overview of the life cycle of the conventional oil and gas onshore exploration, development and production. Descriptions of processes/technologies are presented in this section.

Within modern oil and gas operations it is also possible to extend the life-time of an oil/gas field through the placement and development of additional wells. This extended component would see the second, third and fourth life-cycle stages repeated. The current study covers the risks and impacts for the existing life-cycle stages only; the cumulative effects of additional well placement and drilling are not considered.

Table 2.1: Life-cycle and processes and technologies for onshore conventional oil and gas

Main Stages	Sub-stages	Processes/technologies
Stage 1 - Site identification and preparation	1. Identification of resource (desk study)	**Desk studies** of target area to establish geological conditions and hydrocarbon potential
		Licensing
	2. Surveys and conceptual model	**General investigation:** - Aerial survey of land features e.g. satellite imagery, aircrafts, etc.
		Geophysical testing/investigations: - Land based seismic
		Development of conceptual model
	3. Exploratory drilling	**Baseline surveys** (ecology, hydrology, groundwater, community impact, etc.)

[10] OSPAR Decision 98/3 prohibits the dumping and leaving wholly or partly in place of disused offshore installations in the OSPAR region, although competent authorities may give permission to leave installations or parts thereof in place in certain cases. Likewise, for example, under HELCOM Annex VI, disused offshore units must be entirely removed and brought. Therefore, the term 'abandonment' encompasses the abandonment of sites following decommissioning practices.

[11] Key references referred to for the conventional oil and gas onshore exploration, development and production include Eagle Ford Oil and Natural Gas Fact Book, Marathon Oil; and Environmental Management in Oil and Gas Exploration and Production, UNEP/O&G. Further references are also listed.

Main Stages	Sub-stages	Processes/technologies
		Mobilisation of drilling rig and equipment and people to the drill location
		Site preparation (e.g. site clearing, accessibility, infrastructure)
		Support camp (outside boundary)
Stage 2 - Well design, construction and completion	4. Exploration well construction	**Well pad construction**
		Rig installation
		Drilling of vertical or deviated wells
		Drill cuttings management – Management of cuttings generated
		Cementing and casing
		Well stabilisation
	5. Well testing	**Well testing** (some preliminary testing may be carried out before the well is plugged temporarily)
		Treatment of produced water from exploratory wells
		Revised conceptual model and resource estimate
		Assessment (evaluate technical and economic viability for the whole project and develop plans for production)
	6. Well completion	**Well completion** (screens, valves, etc.)
Stage 3 – Development and Production	7. Field development design (not all necessarily required)	**Field development** (planning and design)**:** - Field development concept - Front-end engineering design - Detailed design
	8. Construction and installation	**Implementation of development plan** - Site clearing - Access infrastructure(i.e. roads, infrastructure)
	9. Hook-up and commissioning	- Well hook-up to production system - Pre-commissioning - Commissioning
	10 Development drilling- if required, once field development in place	**Development drilling** (if required) - Small drilling field - Large drilling field
	11. Hydrocarbon production - hydrocarbon production and processing	**Crude oil and gas processing** - operation of plant and process equipment and maintenance activities
		Well workover – well maintenance, etc.
		Process treatment systems - produced water collection and management
		Utility systems - wastewater and sewage collection and treatment
		Waste handling - waste handling, storage, collection and transport
		Hydrocarbon offtakes - product export,

Main Stages	Sub-stages	Processes/technologies
		onshore pipelines/road tankers **Enhanced recovery (water flooding)** – water flooding to boost production **Enhanced recovery (substance injection)** – steam/miscible gas/polymer injection to boost production **Well stimulation (low volume hydraulic fracturing)** – fracturing to boost production
Stage 4 Project cessation, well closure and decommissioning	12. Decommissioning and rehabilitation planning	**Project cessation, well closure and decommissioning**
	13. Decommissioning of equipment and reclamation	**Plugging of wells** **Removal of well pads** **Waste management**
	14. Rehabilitation	**Site restoration**
Stage 5 Project post closure and abandonment	15. Project closure and abandonment	**Long-term well integrity and monitoring** **Relinquishing licences**

2.4.1.2 Stage 1 – Site identification and preparation

Desk studies

To determine suitable sites for hydrocarbon-bearing rock formations, desk studies such as geological maps, satellite imagery and historical records are initially carried out. Aerial survey or examination of photographs are then to be used to identify promising landscape formations such as faults or anticlines.

Licensing

The licensing rules for oil and gas are set out under the EU's Prospection, Exploration, and Production of Hydrocarbon Directive[12]. EU Member States may also have their own licensing rules. For example, exploratory, appraisal or production of oil and gas in the UK can only take place in areas where the Department of Energy and Climate Change (DECC) has issued a licence under the Petroleum Act 1998 (Petroleum Licence). Exploration licences are initially of limited duration (typically around five years) after which there may be a requirement to return half or more of the licensed area to its original condition. If hydrocarbons are discovered, a separate production licence or production-sharing agreement may be drawn up before development can proceed[13].

An EIA is mandatory for oil and gas exploration and production developments if they are expected to produce more than 500t oil or 500,000m^3 gas per day (Directive 2011/92/EU as amended by 2014/52/EU). It also includes project modifications or revisions that increase production by greater than 500t oil / 500,000m^3 gas per day. For projects below this threshold, surface industrial installations for the extraction of petroleum and gas, and deep drilling operations, the competent authority typically screens these projects to determine whether they are likely to have a significant adverse effect on the environment. In the event that the competent authority does not deem it necessary to conduct an EIA in order to grant the permit, then associated risk management measures may not be applied.

12 https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/oil-and-gas-licensing

13 http://www.glossary.oilfield.slb.com/en/Terms/l/licensing_round.aspx

If EIA is required for an installation, the Member State must ensure that mitigation and compensation measures are implemented and that appropriate procedures are determined regarding the monitoring of significant adverse effects on the environment. This is in order to identify unforeseen significant adverse effects. Such monitoring should not duplicate or add to monitoring required pursuant to Union legislation other than the EIA Directive and to national legislation. The type of parameters to be monitored and the duration of the monitoring must be proportionate to the nature, location and size of the project and the significance of its effects on the environment (Directive 2011/92/EU as amended by 2014/52/EU).

If the screening process determines that an EIA need not be produced for an installation, then monitoring requirements typically fall under national regulation (unless other EU legislation applies, with monitoring requirements, e.g. Extractive Waste Directive). The extent to which requirements are applied to such installations may therefore vary amongst Member States.

Surveys

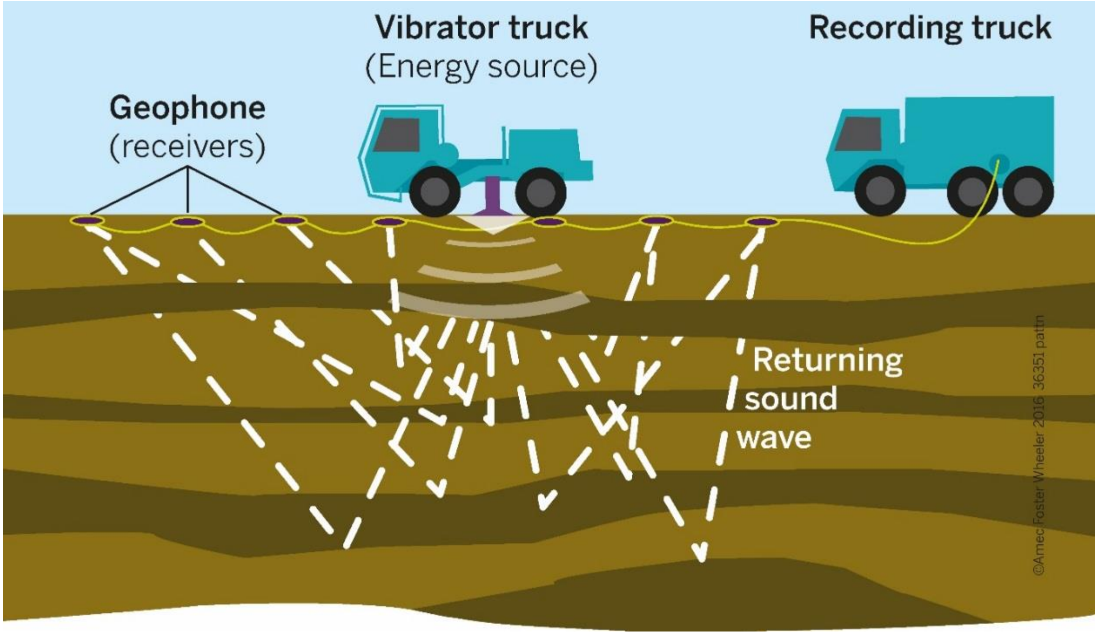
Aerial surveys are conducted to survey land features. Releases to air and noise impacts would occur from aircraft but are short term.

Further detailed information is collected using field geological assessment such as seismic, magnetic or gravimetric surveys. The magnetic method measures the variations in intensity of the magnetic field which reflects the magnetic character of the various rocks present, whereas the gravimetric method involves measurements of small variations in the gravitational field at the surface of the earth.

Seismic survey, often the first field activity conducted, is typically used to identify geological structures. The seismic method relies on the differing reflective properties of soundwaves to various rock strata, beneath terrestrial or oceanic surfaces. Impact on the environment would mainly be from vehicle movements and from generation and recording of seismic data. The activity requires the laying of geophones or seismometers on the surface of the earth or placing geophones in a wellbore (vertical seismic) to record a seismic signal. A source to generate vibrations that travel into the earth may include a vibrator unit, dynamite shot or an air gun[14]. Dynamite was once widely used as an energy source but environmental considerations now generally favour lower-energy sources such as vibroseis (a generator that hydraulically transmits vibrations into the earth, example shown in Figure 2.3) For onshore. Seismic testing methods such as 2D surveys cover extensive areas whereas 3D surveys cover more restricted areas. Regional seismic surveys are 2D surveys with the seismic lines several kilometres apart.

[14] http://www.glossary.oilfield.slb.com/en/Terms/sym/3d_seismic_data.aspx

Figure 2.3: Example of vibroseis process



Based on Reference https://www.utexas.edu/research/cem/vibroseis_research.html

The information gathered is used as an input to a conceptual model of the site.

2.4.1.3 Stage 2 – Well design, construction and completion

Exploration

Once a potential site has been identified, the next step involves drilling a well (also known as an 'exploration' well or 'wildcat') to be drilled to confirm the presence or otherwise of hydrocarbons and the thickness and internal pressure of any potential reservoir. Where a drill site will be situated depends on the characteristics of the underlying geological formations. Baseline surveys (such as ecological, hydrological, groundwater, community impact, etc.) may be required (KLIF, 2011; UKOOG 2015) before drilling takes place.

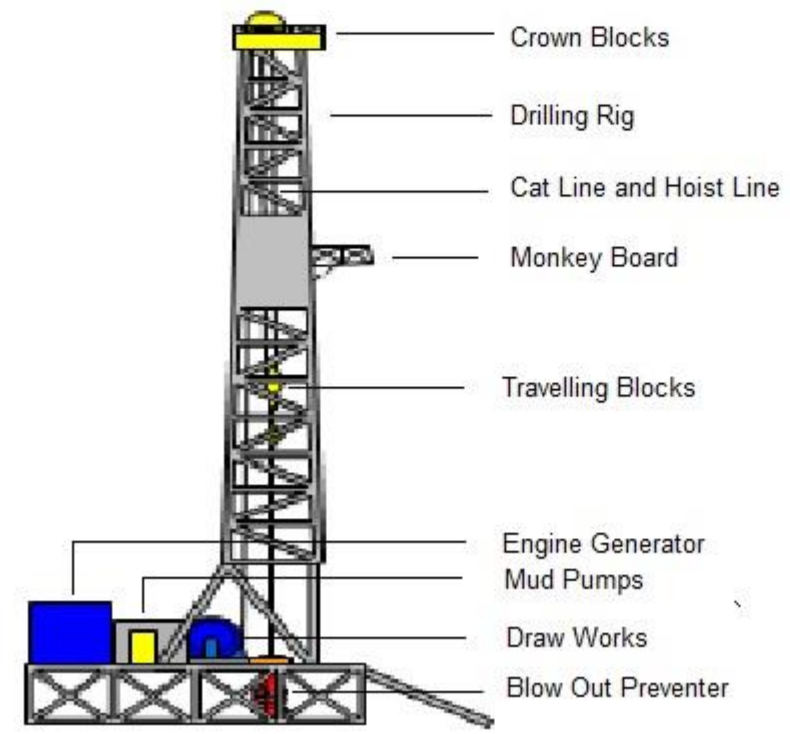
To prepare for well drilling, a pad is constructed at the selected site to accommodate drilling equipment and support services. An onshore pad can occupy an area between 4,000 and 15,000 m^2 for a single exploration well (UNEP/O&G, 1997). In addition to this, further land is needed to support facilities associated with drilling such as roads, pipelines and storage facilities.

Once the pad is constructed, the rig can then be mobilised. Land-based drilling rigs and support equipment are normally split into modules for easier transportation and movement. Drilling rigs may be moved by land or air depending on access, site location and module size and weight. Once on site, the rig and a self-contained support camp are assembled. Typical drilling rig modules include a derrick (scaffold), drilling mud handling equipment, power generators, cementing equipment, and tanks for fuel and water. A support camp (situated nearby, example indicative size 1,000 m^2) is self-contained and provides facilities such as accommodation, canteen for the workforce as well as communications, vehicle maintenance and parking areas and potentially fuel handling and storage areas for the collection, treatment and disposal of wastes.

Drilling

Drilling involves a "drill bit" which digs into the rock formations creating a hole (well) which reaches the oil or gas reservoir. As the hole gets deeper, pipe is added to the drill bit for further digging. These pipe segments are what forms the drill string which is connected to an engine that turns the drill bit to cut the hole. A drilling rig has four main operations: hoisting system (consisting of the derrick, traveling and crown blocks, drilling line and draw works), rotating equipment (consisting of the swivel, the Kelly, the rotary table, the drill pipe, the drill collars and the bit), circulating system (removal of rock fragments or cuttings) and power system (see Figure 2.4). The hoisting system raises and lowers the pipe and supports the drill string controlling the weight on the drill bit during drilling[15].

Figure 2.4: Typical layout of a drilling rig and its modules



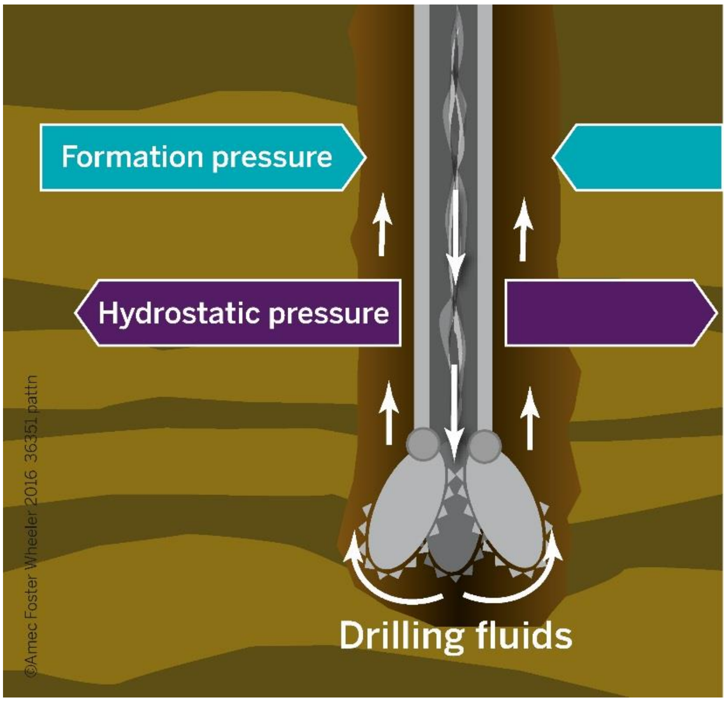
During drilling of vertical or deviated wells, drilling fluid or mud is continuously circulated down the drill pipe and back to the surface equipment. Its purpose is to balance underground hydrostatic pressure, cool the bit (head of the drill) and flush out rock cuttings (Figure 2.5). The drilling fluid also functions to control formation pressures (prevents formation fluid flowing into the well and the loss of control), maintain wellbore stability, cool and lubricate (Don Williamson, 2013). There are a number of drilling fluid types, however the main types are the following:

- Water based mud (WBM);
- Oil based mud (OBM) – also referred as non-aqueous drilling fluid (NADF); and
- Synthetic based mud (SBM) – also referred as non-aqueous drilling fluids (NADF).

Typically, the solid medium used in most drilling fluids is barite (barium sulphate) for weight, with bentonite clays as a thickener.

[15] http://www.petrostrategies.org/Learning_Center/drilling_operations.htm

Figure 2.5: Example of drilling with a drill bit



Based on Reference: http://multimedia.3m.com/mws/media/800467P/oil-gas-website-graphics-drilling.jpg

The risk of an uncontrolled flow from the reservoir to the surface is greatly reduced by using blowout preventers (a series of hydraulically actuated steel rams that can close quickly around the drill string or casing to seal off a well). The cuttings (often the largest quantity of waste stream generation) are filtered out of the drilling fluid system with shale shakers (removal of drilled solids from the mud) and are monitored for composition size, shape, colour, texture, hydrocarbon content and other properties by engineers.

Drilling fluids also contain a number of chemicals that are added depending on the downhole formation conditions. Treatment and disposal of drilling fluids and drilled cuttings may include one or a combinations of the following (IFC, 2007):

- Re-injection of the fluid and cuttings mixture back into a disposal well;
- Injection into the annular space of a well;
- Storage in dedicated storage tanks or lined pits prior to treatment, recycling and/or final treatment and disposal;
- Pre-treatment to render fluid and cuttings non-hazardous to final disposal using on-site or offsite biological or physical treatment[16]; and
- Recycling of spent fluids back to the vendors for treatment and re-use.

Case installation ("Cementing and Casing")

Steel casing is run into completed sections of the borehole forming a continuous hollow tube and cemented into place[17]. The casing provides structural support, protects the wellstream from outside contaminants as well as fresh water reservoirs

[16] Established pre-treatment methods include thermal desorption (TDU) to treat NADF for re-use, bioremediation, or solidification with cement and/or concrete. Final disposal routes for non-hazardous cuttings solid material would be established and may include use in road construction material, construction fill, or disposal through landfill including landfill cover, capping material where appropriate.

[17] http://www.glossary.oilfield.slb.com/en/Terms/c/casing_completion.aspx - Accessed 7 May 2015

from the oil or gas that is being produced. Referred to as a casing programme, the different levels include production casing, intermediate casing, surface casing and conductor casing.

Casing typically comprises a solid string of steel pipe. Should the well contain loose sand that might infiltrate the wellstream, the casing is installed with a wire screen liner that will help to block the sand from entering the well (Rigzone, 2015).

Drilling duration depends on the depth of the hydrocarbon formation and the geological conditions. Operations typically occur 24 hours a day.

Exploratory well testing

Where a hydrocarbon formation is found, initial well tests are conducted to establish flow rates and formation pressure. These tests may generate oil, gas and produced water each of which require management. The management of associated gas often involves flaring or venting to the atmosphere.

After drilling and initial testing, the rig is usually dismantled and moved to the next site. If exploratory drilling has discovered commercial quantities of hydrocarbons, a wellhead valve assembly ('Christmas tree') may be installed. If the well does not contain commercial quantities of hydrocarbon, the site is decommissioned to a safe and stable condition and restored to its original state or an agreed after use. Open rock formations are sealed with cement plugs to prevent upward migration of wellbore fluids. The casing wellhead and the top joint of the casings are cut below the ground level and capped with a cement plug.

Appraisal

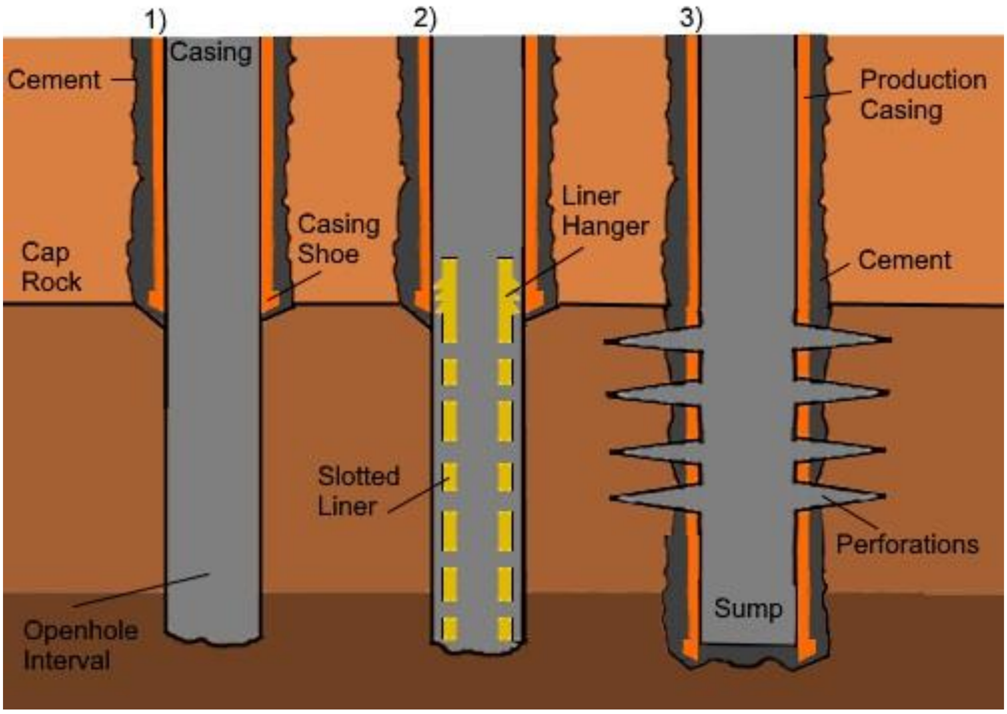
If the exploratory well is successful, more wells may be drilled to determine the size and the extent of the field and confirm whether hydrocarbon can be extracted economically. Wells drilled to quantify the hydrocarbon reserves are called 'outstep' or 'appraisal' wells. The appraisal stage also determines the number of appraisal wells required and whether any further seismic work is necessary. A number of wells may be drilled from a single site. Deviated or directional drilling at an angle from a site adjacent to the original discovery borehole may be used to appraise other parts of the reservoir.

Well completion

When a drilled well is developed into a production well, it must undergo well completion which refers to the assembly of tubulars (oilfield pipes, such as drill pipe, drill collars, pup joints, casing, production tubing and pipeline) and equipment required to enable safe and efficient production of oil or gas. As part of a conventional well completion, a well clean-up takes place, whereby a fluid is pumped down the well to lift fluids, sands, particles and drilling cutting out of the well bore. This process lasts for several days, known as the 'flowback period'. During the flowback period natural gas is often produced from the well alongside debris and fluid. This gas is separated from the other materials and if there is no infrastructure available to store or transport it, it is either flared or vented to atmosphere, depending on regulatory requirements and other factors (IPIECA, 2015).

Well completion also entails cementing of the well (Figure 2.6). Cement slurry is pumped into the well displacing any existing drilling fluids and spaces are filled between the casing and the sides of the drilled well. With mixtures of additives and cement, the slurry hardens sealing the well and permanently positioning the casing into place. The wells are then completed as open-hole or cased-hole. An open-hole completion refers to a well that is drilled to the top of the hydrocarbon reservoir. The well is then cased at this level, and left open at the bottom. Cased-hole completions require casing to be run into the reservoir. To achieve production, the casing and cement are perforated to allow the hydrocarbons to enter the wellstream. Finally, a gravel pack to prevent sand from entering the wellstream and a production tree (wellhead) are installed to fully complete a well[18].

Figure 2.6: Well completion and cementing of the well



Based on Reference: http://hmf.enseeiht.fr/travaux/CD0910/bei/beiep/images/4.gif

Completion fluid

A solids-free liquid is used to complete an oil or gas well. The fluid is run through the well to facilitate final operations prior to initiation of production. The fluid provides control should downhole hardware fail, without damaging the producing formation or completion components[19].

2.4.1.4 Stage 3 – Development and production

Development

Development refers to the expansion of exploration wells into a full field for production purposes. Planning is performed to fully and efficiently exploit the oil or gas field, and may involve the drilling of additional wells[20]. The number of wells will depend on the proven quantities of oil and/or gas discovered. The level of development activity is hence proportional to the number of wells drilled, including support services required and time during which the site is operational. As each well is drilled it has to be prepared for production before the drilling rig departs.

Site infrastructure may include the following: access, storage and waste disposal facilities, wellheads; flowlines; separation/treatment facilities; soil storage; facilities to

[18] http://www.rigzone.com/training/insight.asp?i_id=326#sthash.enlARq9R.dpuf
[19] http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=completion%20fluid
[20] http://www.glossary.oilfield.slb.com/en/Terms/d/development.aspx

export product; flares; gas production plant; accommodation, infrastructure; transport equipment; well pads; enhanced recovery systems; and product export facilities.

Heavy drill pipe is replaced by a lighter weight tubing in the well. A single well may carry two or three strings of tubing, each one producing from different locations within the reservoir.

Hook-up and commissioning

Hook-up[21] and commissioning testing are carried out to ensure the well is suitably completed for commercial production. Hook-up ensures that all systems are correctly installed and tested. Once this is completed, pre-commissioning is undertaken to ensure the system is functional. Once satisfied, full commissioning will take place with the hydrocarbon is introduced up the well and into the production system (Amec Foster Wheeler, 2015b).

Commissioning refers to activating the system once it is hooked up. Connections are checked with pressure tests, and it is verified that the separator and the controls are working as required (Harvey, 2014).

Well pressure and flow rates depend on a number of factors including the properties of the reservoir rock, hydrocarbon viscosity/pressure and the gas to oil ratio (GOR). It is common to inject gas, water or steam into the reservoir at the start of the field's life to maintain pressures and optimise production rates and the ultimate recovery potential of oil and gas.

These factors fluctuate, eventually leading to a fall in productivity over the commercial life of the well. Later in field life, assistance is typically required to draw hydrocarbons to the surface. This may be in the form of enhanced recovery such as via a pumping mechanism or the injection of gas or water to maintain reservoir pressures.

Field development results in a significant expansion on any site infrastructure that would have been put in place for exploration drilling. A large amount of design and planning is necessary for such developments, in which well sites are nested within a central area which includes an array of processing facilities, offices and workshops. Such developments can potentially occupy an area of up to several hectares depending on the capacity of the field. Since production is typically of significantly longer duration than exploration, the temporary facilities used for exploration are replaced by permanent facilities all of which are subject to detailed planning, design and engineering and construction (UNEP/O&G, 1997).

Production

As soon as the hydrocarbon reaches the surface, it is routed to the central production facility which gathers and separates the produced fluids (oil, gas and water). The size and type of the installation will depend on the nature of the reservoir, volume and nature of the produced fluids and the export option chosen.

The production facility processes the hydrocarbon fluids and separates oil, gas and water. The oil must be free of dissolved gas before export. In gas fields, the gas must be stabilised and free of liquids and unwanted components such as hydrogen sulphide and carbon dioxide. Any produced water that is generated will be treated before disposal.

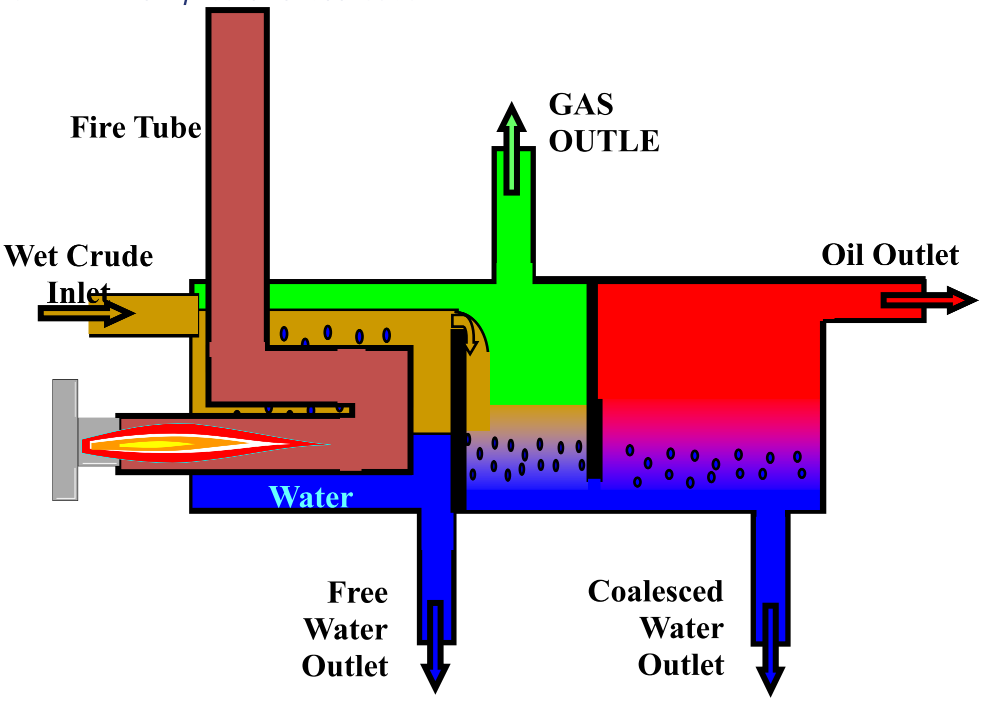
Several separator stages are conducted each with reducing pressure to allow controlled liquid recovery and stabilised oil and gas and to separate water. The main

[21] "Hook up" refers to making the connections from the well to the oil and gas separator and from the separator to either the storage tanks or a flow line. It also includes connection of the utilities needed for the controls to function.

separators are gravity types. This works by reducing the well pressure with production choke to the high pressure (HP) manifold. The first stage separator reduces the pressure to around 3-5 Mpa and temperature of 100-150°C. The second stage separator uses a reduced pressure of around 1 Mpa and temperature below 100°C. The water content is reduced to below 2%. The third and final separator is a two-phase separator ("flash drum") which reduces pressure to around 100kPa so that the last heavy gas components can boil out. Produced water may be generated in large quantities where water content is high during the separator stages. The water 'cut' or proportion of water to oil produced from the well increases over its lifetime, as pressure falls and additional water is introduced during secondary recovery. Typical water cut ranges from 25% or lower at the start of production (1 barrel of water produced per 3 barrels of oil) to 75% or higher later in production (3 barrels of water produced per 1 barrel of oil). Often this water contains sand particles bound to the oil/water emulsion which requires treatment.

For oil production, after the separation stages, the oil can go to a coalescer for final removal of water. If there are high quantities of salts, these can be removed in an electrostatic desalter, illustrated in Figure 2.7.

Figure 2.7: Examples of a coalescer



Gas is treated and compressed through several stages. The gas is first cooled in a heat exchanger which allows the compressor to operate more efficiently. The lower the temperature, the less energy will be used to compress gas. The scrubber then removes the liquid from the gas to prevent erosion of the compressor's fast rotating blades. Once cooled and liquid is removed, the gas is compressed before this is introduced into the pipeline network or storage (Devold, 2013).

Typical operations on a producing well include a number of monitoring, safety and security programmes, maintenance tasks and periodic downhole servicing using a wire line unit or a workover rig to maintain production. Well workover is carried out to repair or stimulate an existing production well for the purpose of restoring, prolonging or enhancing the production of the hydrocarbons[22].

[22] http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=workover

There are many other systems that are associated with oil and gas production. Utility and waste management systems do not handle the hydrocarbon process flow but they provide services necessary for the main process safety or residents. Depending on the location of the installation, functions such as electricity may be available from nearby infrastructure, otherwise for remote installations, these would be self-sustaining with its own power plant, water, etc. (Devold, 2013).

On-site power plants typically consist of a set of reciprocating engines or a gas turbine. These are fuelled with imported diesel or in some cases crude oil / associated gas produced from the field. This results in significant emissions of GHGs and local air quality pollutants. It also generates noise and increases the land take or platform size required for the operations. Furthermore, generation running on imported fuels increases the environmental impact of logistics associated with the exploration and production site.

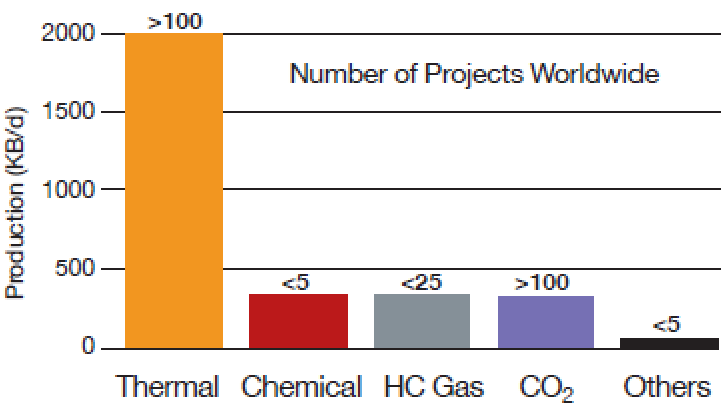
Enhanced recovery

Overview of enhanced recovery

In this report, enhanced recovery (ER) refers to techniques for both oil and gas fields. Enhanced oil recovery (EOR) is defined as a subset of ER which encompasses ER techniques that are applied only to oil fields.

As the production of conventional oil or gas is depleted, the remaining hydrocarbon resource becomes more difficult to recover. Enhanced recovery (ER) methods are often employed to increase hydrocarbon production rates. These can boost the recovery factor of an oil reservoir to up to 30 – 60% (US Department of Energy, 2016). There are a wide variety of ER techniques available that are tailored to properties of different formations and hydrocarbons. There are four main categories for oil and gas fields: water flooding, thermal recovery, gas injection, chemical injection. Within these categories there are a great number of technologies at varying stages of development and deployment in the oil and gas industry. Water flooding is considerably more mature than other forms of ER, and is therefore often classified as a 'secondary' enhanced recovery technique, with the other more advanced techniques known as 'tertiary' enhanced recovery techniques. Enhanced recovery techniques are very sensitive to economics, as the marginal cost of extracting oil rises significantly once they are employed (Alvardo et al, 2010). For this reason, the current levels of deployment of ER techniques is not indicative of their maturity, due to fluctuations in the prices of oil and gas, amongst other factors. As of 2010, thermal ER was the most widely applied form of tertiary ER globally (see Figure 2.8).

Figure 2.8: Number of ER projects worldwide in 2010



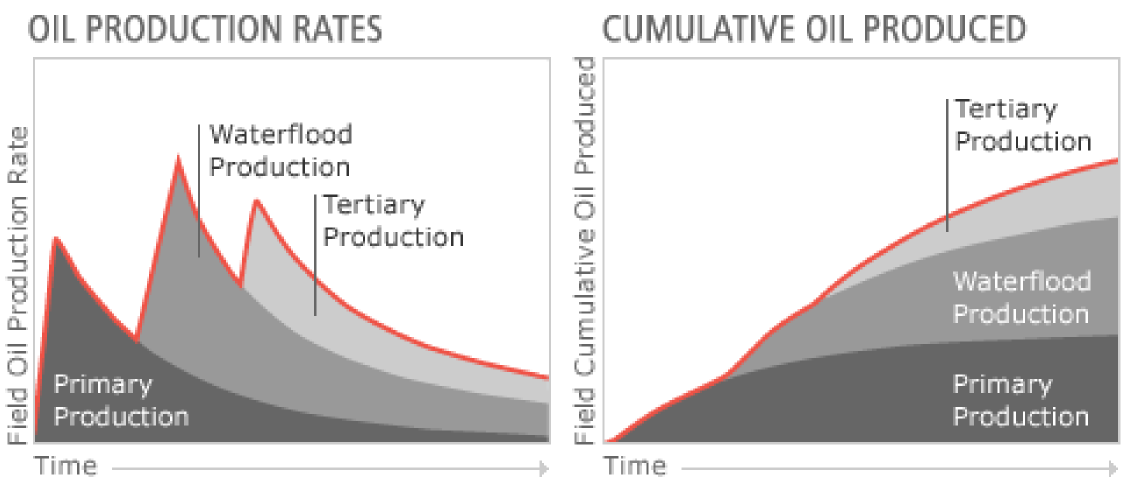
Reference: http://www.world-petroleum.org/docs/docs/publications/2010yearbook/P64-69_Kokal-Al_Kaabi.pdf

In 1986 world's oil production using tertiary ER methods was about 77 million US tons. In 2010 it was estimated as closer to 110 million US tons (Petros, 2010). Using the value of global oil production in 2010, quoted in Petros (2010) at 68,963 thousand barrels a day, the proportion of total oil production from tertiary ER in 2010 was roughly 3%. It is unclear to what extent tertiary ER technologies are being applied to conventional oil and gas wells in Europe, although their deployment is expected to increase over the coming years, particularly with the long-term trend of rising oil prices. In March 2016, several Member States indicated to the Commission that enhanced recovery techniques (steam injection, water flooding and gas injection) were occasionally used in their conventional oil and gas fields. There were also reported cases of low volume hydraulic fracturing in conventional oil and gas extraction, however, it was not specified whether this occurred onshore or offshore.

Water flooding

Generally, conventional oil production spans three main phases. The primary phase relies on the natural pressure of the reservoir or gravity that drives the oil into the well bore. Man-made lifting techniques such as pumps aid bringing the oil to the surface. Depending on the viscosity of the oil, the porosity and wettability of the containing formation and the properties / amount of water in the formation, approximately 10-20% of the total reserve may be recovered in this manner (EPRI, 1997). The second and third phases of production involve enhanced recovery. In the secondary phase a technique known as water flooding is employed. This involves injecting water into the reservoir. This has been practised for over 100 years and is considered a mature and relatively inexpensive process in the oil and gas industry (Satter et al., 2008). The water displaces some of the stagnant oil and boosts production, increasing the recovery factor of the reservoir to 30 – 40%. In some cases it may be economical to re-inject produced water from wells rather than utilising freshwater reserves. It is assumed that water flooding is applied in a high proportion of oil wells in the EU, but no exact quantification could be found.

Figure 2.9: The three phases of oil recovery



Reference: http://zargon.ca/operations/oil-exploitation/

Because natural gas has a low viscosity compared to oil, water flooding is not typically employed for a gas well. Gas wells therefore have just two production phases: primary production and enhanced recovery.

Chemical injection

Chemical injection involves introduction of chemicals into the well, typically alongside water. Chemicals used consist of polymers, surfactants and/or alkalis. Polymers are long chains of molecules that increase the viscosity of injection water, thus increasing the effectiveness of water floods. Surfactants help to lower the surface tension between formation water/rock and oil that prevents oil droplets from moving through a reservoir. Alkalis penetrate deep into hard-to-reach areas of the formation, where they react with acids in the crude oil to form surfactants in-situ. Chemicals used and their volumes vary greatly depending on the application, therefore no generalised indication can be given as to the volume or toxicity of chemicals generally used in ER.

In 2012 chemical ER represented just over 10% of the global ER market (Offshore Engineer, 2014). Chemical ER faces significant challenges, especially in light oil reserves. This is partly due to a lack of compatible chemicals in high temperature and high salinity environments (Kokal et al, 2010). Polymer flooding is considered a mature technology and was developed during the high oil prices of the 1980s. However, Since the 1990s, it has been in decline and is currently only practised significantly in China (Alvardo et al, 2010). However, there were reportedly plans to implement a polymer flood in the Bochtsted field in Germany. Surfactant injection remains challenging, especially in high salinity high temperature environments (Kokal et al, 2010). Alkali and combinations of chemicals have been tested in a limited number of fields (Alvardo et al, 2010).

Thermal recovery

Thermal recovery involves introducing heat into the reservoir, in order to reduce the viscosity of oil and improve its ability to flow through the reservoir. For this reason, it is particularly suited to heavy, viscous crudes. Methods rely on either steam/hot water injection, or in-situ combustion. Steam/hot water injection involves flooding the reservoir with high temperature water. In-situ combustion processes inject air into the reservoir, to enable the hydrocarbon reservoir to ignite. This generates heat internally and also produces combustion gases, which enhance recovery. The combustion is carefully controlled through the quantity of air injected.

In 2012 thermal ER represented over 50% of the ER market, with the US and Canada conducting the majority of thermal ER projects (Offshore engineer, 2014). Steam injection is the mature form of thermal ER and has been the most widely used enhanced recovery method for heavy and extra heavy oil in sandstone reservoirs during recent decades (Alvardo et al, 2010). In 2007, steam injection was reportedly being used at the Schoonebeek field in the Netherlands. In-situ combustion projects have been reported, but are not as widespread as steam injection and remain in a development stage (Kokal et al, 2010). There is a reported case of in-situ combustion in use in heavy oil fields in Suplacu de Barcu, in Romania (Alvardo et al, 2010).

Gas injection

Gas injection introduces gases such as natural gas (where no infrastructure for processing is available), nitrogen, or carbon dioxide (CO_2) into the reservoir. These expand to push additional oil to a production wellbore (immiscible gas flooding). Additionally, these gases may dissolve in the oil to lower its viscosity and improve its flow rate, known as miscible gas flooding. Gas injection may also be combined with water flooding in a process known as water and gas injection (WAG). Injections of water and gas are either alternate or simultaneous. The three phase flows of water, oil and gas is more effective at displacing residual oil than a two phase system. Gas injection is not applicable to gas fields.

In 2012 gas injection represented 35% of the enhanced recovery market. Immiscible gas floods using N_2 have been reported but are not common (Alvardo et al, 2010). Miscible gas flooding using CO_2 or natural gas is considered a mature enhanced recovery technology. CO_2 flooding has been the most widely used EOR recovery method for medium and light oil production in sandstone reservoirs during recent decades, especially in the U.S. due to the availability of inexpensive and readily available CO_2 from natural sources (Alvardo et al, 2010). Pilot CO_2 injections were held in Ivanic field in Croatia in 2001-2006. Furthermore, Hungary has several decades of experience of CO_2 injection, with developed projects at the Budafa, Lovvaszi and Szank fields. The latter uses CO_2 produced from industry, rather than natural sources. The uptake of this form of EOR is expected to increase in line with the deployment of carbon capture and storage (CCS) technologies, as this will significantly reduce the price of CO_2. Gas injection using hydrocarbons is common in settings where there is no infrastructure available to process produced gas.

Well stimulation

Well Stimulation is the process of cleaning the available flow channels or creating new flow channels with in the rock formation to improve permeability. Well stimulation boosts the flow of hydrocarbons to the wellbore to increase productivity (Petropedia, n.d.). The specific well stimulation technique relevant to conventional well considered in this report is hydraulic fracturing in low volumes (HVHF having been addressed in previous studies).

Low volume hydraulic fracturing

Hydraulic fracturing (HF) is a technique in which the formation that contains hydrocarbons is fractured using a pressurised liquid. Fracturing fluids, consisting of water, proppants and a thickening agent, are injected into the well to form cracks that enable hydrocarbons to flow more freely. This process is used in some conventional oil and gas wells in (relatively) low volumes as a well stimulation method, but it is unknown to what extent it has been deployed in this context. For comparison, Gallegos et al. (2015) reports that median annual volumes of 15,275 and 19,475m^3 of water per well were used to fracture horizontal oil and gas wells respectively, compared to less than 2600m^3 used in vertical and directional wells. As discussed in Amec Foster Wheeler (2015a), the distinction between conventional and unconventional wells is somewhat arbitrary, but UFFs tend to utilise more horizontal wells than CFFs.

Hydraulic fracturing is commonly used in gas fields but may also be employed for tight oil reservoirs. Once fracturing has occurred, ER methods may also be employed to increase production.

Summary

It is concluded that the ER and well stimulation technologies recognised as mature in the oil and gas industry are polymer injection, steam injection, miscible gas injection (CO_2/HC) and low volume hydraulic fracturing. Therefore, these are the processes for which risks and impacts are considered under the 'enhanced recovery' and 'well stimulation'; sub-stages for conventional onshore activities. For offshore activities, only miscible gas injection using hydrocarbons gas and low volume fracturing are considered mature (see 2.4.2 – stage 3 production). It should be noted that, unlike other sub-stages, only a proportion of wells are using ER/well stimulation; therefore the associated risks of these processes only apply to such wells and not systematically to all conventional wells. No quantification of the proportion of wells currently applying ER in Europe could be found, but it is expected that ER/well stimulation deployment will increase in the future, as R&D progresses and hydrocarbon prices rise.

2.4.1.5 Stage 4 – Project cessation, well closure and decommissioning

Decommissioning of onshore production installations at the end of their commercial life (typically 20 – 40 years) requires removal of buildings and equipment, restoration of the site and implementation of measures to encourage site re-vegetation. It may also include continued monitoring of the site after closure. Planning for decommissioning is an integral part of the overall management process and should be considered at the beginning of the development during design. Frequently, exploration wells will be unsuccessful and decommissioned after one to three months of activity. Planning for decommissioning activities should be conducted from the outset of the project to ensure minimal environmental disruption (UNEP/O&G, 1997 and IFC, 2007).

2.4.1.6 Stage 5 – Project post-closure and abandonment

Once the well is decommissioned, the site may then be monitored (for monitoring details refer to 2.4.1.2 – Licensing) to ensure the structural integrity of the well is maintained and that there are no leakages into or from the well. Once the monitoring period is completed, all licences are relinquished. In the case that the owner of the well cannot fund proper decommissioning, liability for the proper abandonment of the well and long-term well integrity may fall to the competent authority. These wells are known as 'orphan wells'.

2.4.2 Offshore

2.4.2.1 Overview

Offshore exploration and production follows the same five life-cycle stages detailed for onshore oil and gas. However many of the physical practicalities of working offshore and inherent risks attached to these activities differ from those for onshore sites. Table 2.2 provides a summary of the processes and technologies used for each of the life-cycle stages. A more detailed narrative of the specific stages and processes utilised for offshore oil and gas is detailed after Table 2.2.

Table 2.2: Life-cycle and processes and technologies for offshore conventional oil and gas

Stages (AEA)	Main stages	Processes/technologies
Stage 1 - Site identification and preparation	1. Desk studies and licensing	**Desk studies** of target area for favourable geological conditions **Licensing**
	2. Exploratory Surveys	**General investigation:** Gravity and magnetic surveys by boat to capture geological information and identify 'leads' for further exploration. **Geophysical testing/investigations:** Seismic surveys – shock waves are sent into the subsea geological formations and response times monitored for returned waves to further identify and define reservoirs.
Stage 2 - Well design and construction	3. Well design	**Desk studies** for well design, planning and logistics
	4. Transport of drilling rig	**Transport of drilling rig** – vessels,
	5. Well drilling	**Positioning of drilling apparatus –** Seabed activities **Drilling of vertical or deviated wells –** Drilling with water based mud (WBM)/ Oil Based Mud (OBM)/Synthetic Based Mud (SBM) **Drill Cuttings Management –** Management of cuttings generated
		Cementing and Casing– Cementing of well casings

Stages (AEA)	Main stages	Processes/technologies
	6. Well completion	**Well bore clean-up** - handling potentially contaminated wastewater and solids/cuttings **Introduction of completion fluids –** Introduction of chemicals to protect the well including corrosion inhibitors and biocides
Stage 3 - Production	7. Platform installation	**Engineering, Procurement and Construction (EPC) – facility design and construction –** Onshore/nearshore activities to prepare platform for particular drilling site. **Transport of platform** – shipping vessels **Piling for jacket foundations/anchor points**-seabed activities to permanently install fixed platforms and/or floating production facilities **Rock dumping** - depending on rig type may be necessary to use rock dumping as part of foundation design. **Hydrostatic testing –** leak and pressure testing of production and utility systems **Subsea infrastructure –** installation of subsea equipment as necessary including Includes ESPs, hydraulically-powered pumps, FLETS, PLETS, ESDVs, pigging equipment, manifolds, and X-trees. Also includes in-field flowlines, injection lines and umbilicals, but excludes piling **Pre-commissioning** – Pressure testing, hydro-static leak testing
	8. Platform operations	Platform operations are divided into three categories: i) Production, ii) Topside utility systems and iii) Export systems **I Production:** **Chemical injection** – Use of chemicals to maintain well bore. **Subsea production systems –** For larger networks tie-backs and sub-sea equipment has to be installed and maintained. **Oil/gas processing and handling** – processing of extracted material to separate oil, water and gas **Produced water management –** Treatment and processing of the water generated from reservoir fluid separation processes. **Produced sand management –** Washing and cleaning of contaminated sand before return to sea or return to shore **Off-gas management – flaring –** management of gas generated from separation processes **Enhanced recovery (water flooding)** – water flooding using seawater to boost production **Enhanced recovery (miscible gas injection)** – injection of miscible produced HC gas to boost production.

Stages (AEA)	Main stages	Processes/technologies
		Well stimulation (low volume hydraulic fracturing) – fracturing to boost production
		II Topside utility systems: **Power generation and combustion equipment** - Main energy generation units for power on the platform, auxiliary power generation for process equipment **Hydrocarbon and chemical Storage –** Includes both bunkered fuel for power generation and processed oil **Diesel/chemical deliveries/loading** – Includes all receiving shipments of goods to the installation **Open loop sea water cooling –** Seawater cooling systems for all thermal processes carried out on the platform **HVAC systems –** air conditioning systems for accommodation block and equipment **Topside drainage systems** – Covers sewers fir grey and black water, closed systems for process equipment and open systems for drainage on deck **Waste management –** Covers all waste aspects not detailed already, principally drainage, solid waste management and return of material to shore
		III Export systems: **Off-take – vessels –** Off-take of oil to shuttle tankers **Gas/oil export pipelines** – off-take of gas/oil via pipeline
Stage 4 Project cessation and well closure	9. Well closure	**Well Plugging –** Closure of the well bore at multiple points using cement plugs **Conductor recovery** – Recovery of the conductor from the well and return to the surface, may require cutting operations as necessary.
	10. Management of cuttings piles	Leave in place – Management options for leaving cuttings in place. Excavate to surface – Remove of cuttings piles to surface for return to shore Excavate and redistribute on seabed – Options for redistribution of cuttings across the seabed
Stage 5 Post closure and abandonment	11. Topside and jacket decommissioning	**Preparation of topside for removal –** All clean down and removal processes to prepare topside for decommissioning and removal. **Dismantling of structures –** Dismantling of structures in preparation for removal of topside structures **Cutting of leg structures –** Cutting of platform legs to remove the topside structure. **Leave in-situ components –** Footings and base structures to be left in place

Stages (AEA)	Main stages	Processes/technologies
	12. Decommissioning seabed infrastructure, e.g. pipelines/bundles	**Leave in place –** Option to leave pipelines in place, may require further rock dumping. **Partial removal –** Removal of concrete mattresses and non-vital support structures **Full removal –** full removal of pipelines using jet washers to untrench pipelines where necessary.
	13. Shipping	**All decommissioning activities –** Multiple shipping activities as required for decommissioning processes
	14. Long-term well integrity	**Monitoring** - the risks of long-term well integrity failure

2.4.2.2 Stage 1 – Site identification and preparation

Desk studies

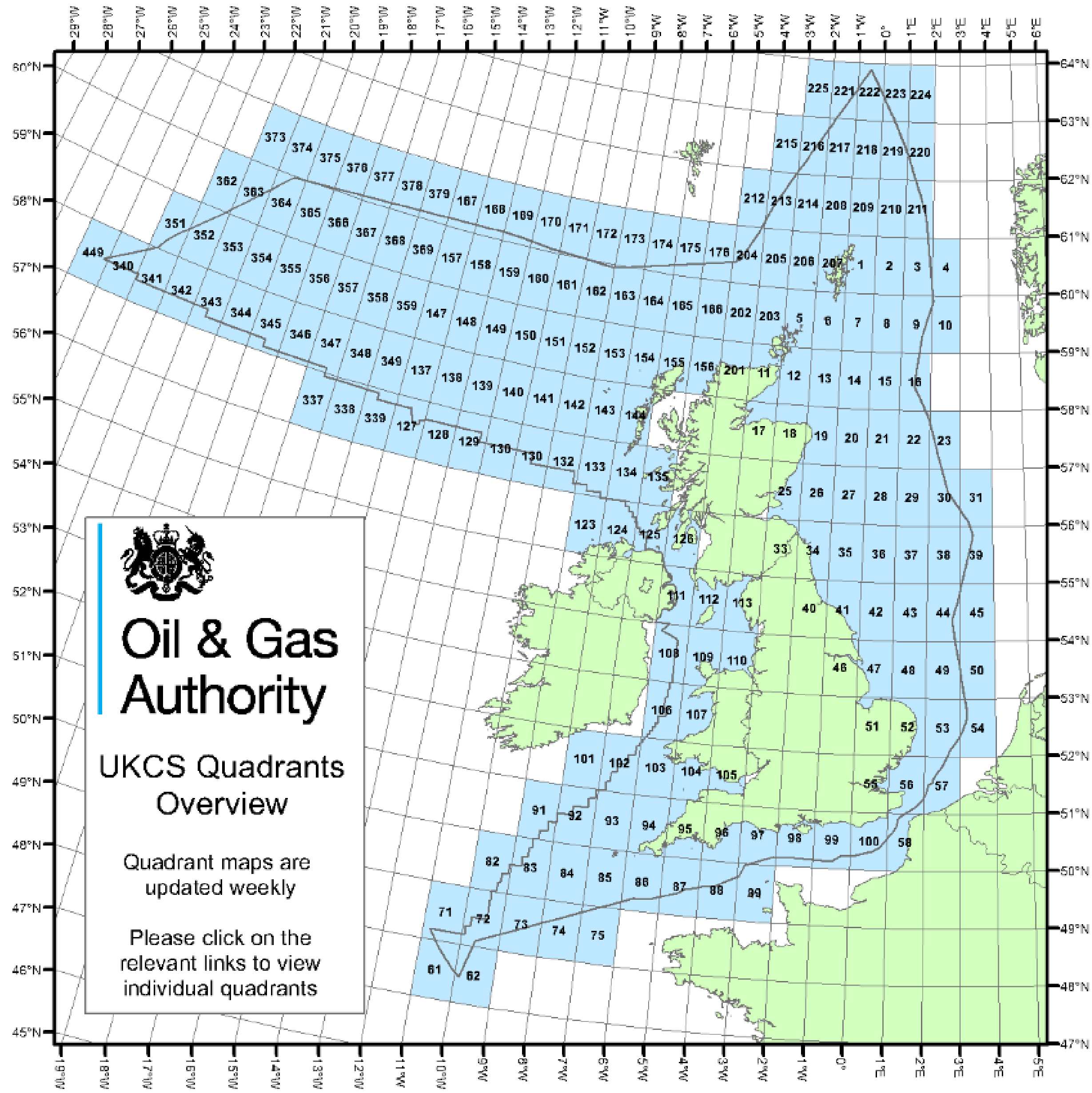
To identify potential hydrocarbon-bearing rock formations, desk studies such as geological mapping, satellite imagery, and reviews of historical records are initially carried out.

Licensing

As with onshore oil and gas, the licensing rules are set out under Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorisations for the prospection, exploration and production of hydrocarbons. Additionally offshore territories are managed through the use of defined geographic areas which are based on a system of what are often termed 'blocks' (UK DECC,2015b) and managed by those countries with a connected shoreline to each set area. As an example, the North Sea represents the largest production area for offshore oil and gas within Europe and is managed by five countries (Denmark, Germany, Netherlands, Norway and the UK), who oversee exploration within their territory based on this gridded system (OCD 2010). Each block is based on 1° by 1° area of seabed (with the exception of Germany and the Netherlands who share an area and work with smaller sized blocks '10 minutes by '20 minutes). An example of such a gridded area is provided in Figure 2.10 for the UK.

Within the Mediterranean, a similar licensing scheme using gridded areas and blocks is used (OEI 2012). This includes gas fields identified off the coast of Cyprus and Greece which began exploration in 2011 (OEI 2012). Exploration licences are typically made available through licensing rounds which are held periodically (OCD 2010) and are initially limited in duration (about 5 years (Schlumberger, 2015)). After which there might be a requirement to return half or more of the licenced acreage to the state. If hydrocarbons are discovered, a separate production licence or production-sharing agreement (PSA) is usually drawn up before development can proceed (Schlumberger, 2015).

Figure 2.10: Quadrant map for UK offshore territories



Reference: UK Department of Energy and Climate Change (DECC) Offshore licensing portal https://itportal.decc.gov.uk/web_files/gis/quadmaps/quadmaps.htm

Surveys

The identification of oil and gas reserves is carried out using sophisticated surveying exercises to assess the geological structure below the seabed. This can be aided using the quadrant maps produced for the gridded map which will detail existing oil and gas fields identified. Ships are used to carry out gravity or magnetic surveys (Devold, 2013) which provide detailed imaging of the subsurface geology. These maps are used to identify potential leads for further analysis.

Potential sites are then subject to further seismic surveys, a process which involves directing sound waves into the sub-surface geology (Devold 2013 and OCD 2010). The time delay between sound waves being fired and returned is measured to provide further imaging of the subject geology. Specifically these surveys look for geological structures capable of holding oil and gas.

The final stage within site identification includes the drilling of exploratory wells ('wildcats') to confirm positive identification of oil and gas deposits. As drilling for exploratory wells and drilling for production cover a similar set of processes, 'drilling' is discussed in its entirety within lifecycle stage 2 below.

2.4.2.3 Stage 2 – Well design and construction and well completion

Overview

During the course of offshore oil and gas development drilling of both exploratory wells and production wells takes place, including 'workovers' of existing wells. This section covers 'drilling' in its entirety, but each sub-stage and process clearly demarks whether it relates to drilling for exploration, production or both.

Well design

The initial stage in exploration is well design based on the results of the previous surveying and leads. This is a planning phase to design the specific nature of the well to geological conditions, the logistical elements of planning and preparation for work at sea.

Selection and transport of drilling rig to site

The choice of offshore facility used for exploration drilling varies depending upon the practical issues faced, such as water depth, logistical issues and cost of equipment that best meets the needs of the operator.

Exploration wells are typically drilled using Mobile Offshore Drilling Units (MODUs) which, as the name suggests, are capable of drilling multiple wildcat wells within a license. Production wells are typically drilled once more permanent features of a field development are in place, and a description of production installations given in stage 3 (production) of the lifecycle.

MODUs are vessels equipped with many of the requirements of a marine vessel, as well as the infrastructure for drilling offshore wells. They have a drill floor typically located centrally on topsides, around which is positioned a drilling derrick, in much the same configuration as would be expected for onshore drilling. MODUs house a number of key elements required for drilling including mud rooms, space for storage of drill pipe and downhole equipment, lifting equipment, and a range of utilities systems.

Example MODUs used for exploration drilling include:

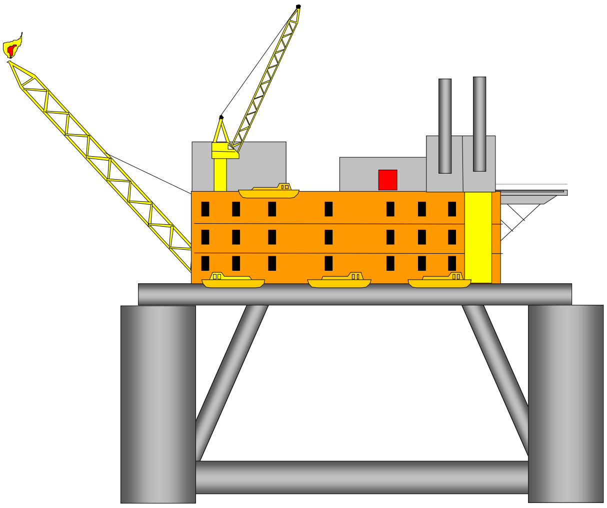
i) *Semi-submersible* – vessels that make use of ballast tanks to manage their buoyancy and depth during drilling. Semi-submersibles are able to mobilise to site under their own propulsion systems, and are then held in place on site using anchoring or dynamic positioning systems (OCD, 2010);

ii) *Jackup Rigs* – temporary installations transported by shipping vessel to the drilling site and then positioned onto the seabed using extendable legs, with the topsides remaining above sea level. Jackup rigs tend to be best suited to more shallow waters (ABS, 2000); and

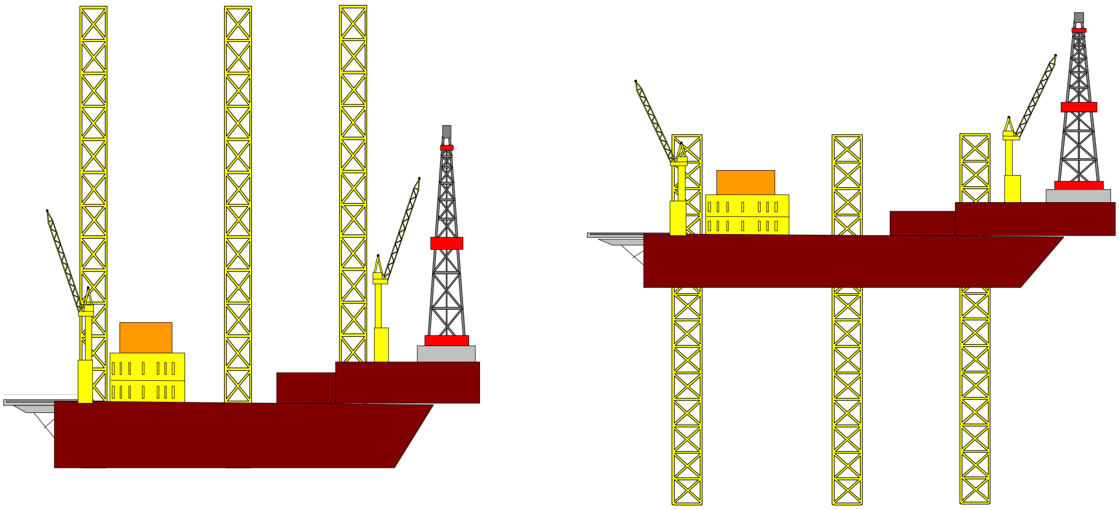
iii) *Drill Ships* – shipping vessels which carry the equipment on board necessary for carrying out drilling activities in a similar manner to semi-submersible and jackups. A key difference between semi-submersible vessels and drill ships is that they are ship-shaped and are able to operate in deeper water (up to 4,000 metres) making use of dynamic positioning to remain stable (ABS, 2000).

Examples of all three types of MODU are provide in Figure 2.11.

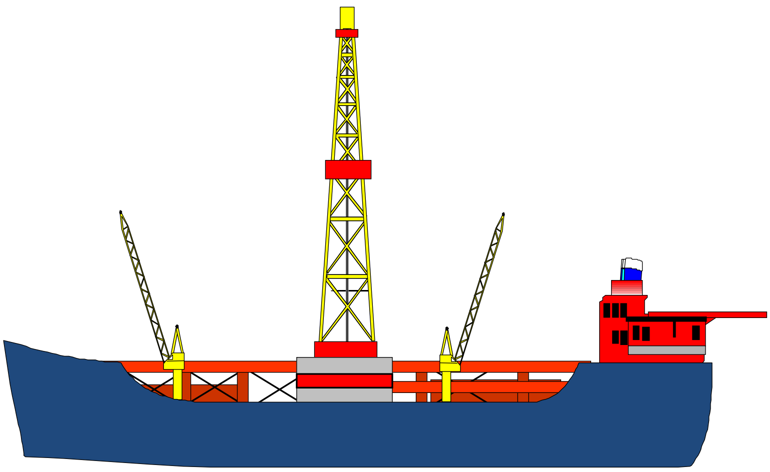
Figure 2.11: Examples of semi-submersible, jackup rigs and drill ships



Semi-submersible vessel



Jackup Rig



Drill-ship

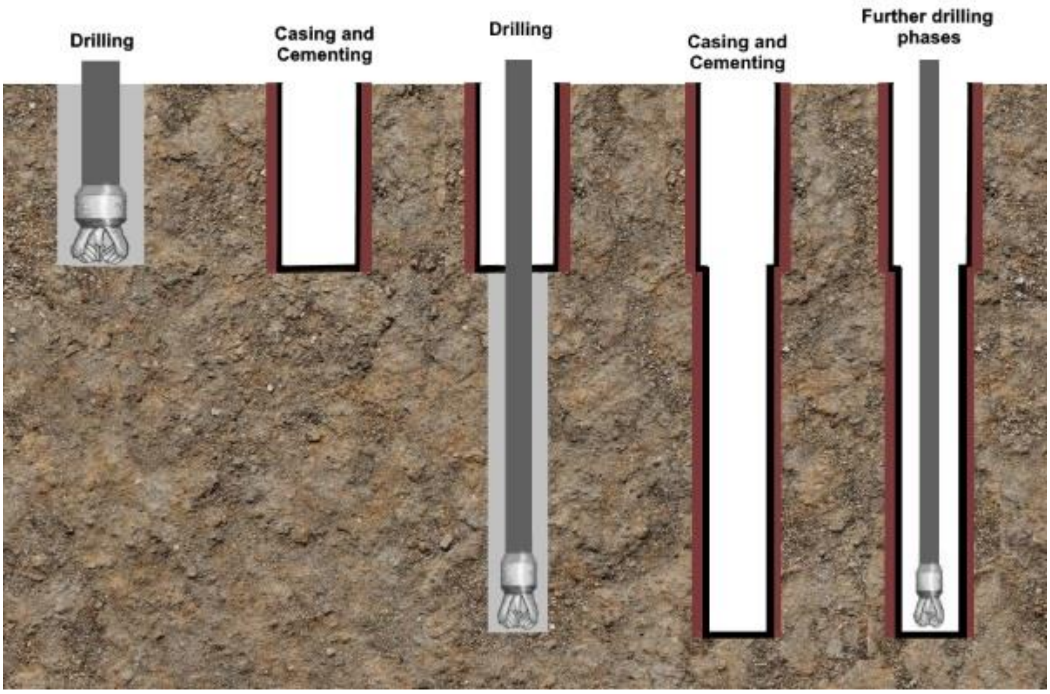
Well drilling

Drilling begins once the drill rig has been mobilised and satisfactorily installed at the proposed well site. A steel template is placed on the seabed and held in place with piling to help guide the drilling. The drilling equipment is made up of a drill head and drill pipe which is fed into the well bore as drilling progress, supported by the drilling derrick (scaffolding) on topsides.

A blow-out preventer is used as an emergency system to ensure that, in the event of failure of primary well control systems, over pressurisation does not result in a loss of containment of well fluids (a 'blowout').

Drilling is typically completed in phases commencing with wider bore drills typically between 13 and 76 cm in diameter (OCD, 2010). At the completion of each phase of drilling, steel casing slightly smaller than the hole is inserted and cemented into place to protect the integrity of the well before another phase of drilling with smaller bore drills. Modern wells typically have 2 – 5 phases of drilling (OCD, 2010), resulting in a tapered well shaft as shown in Figure 2.12.

Figure 2.12: Well drilling



Based on Reference OCD 2010

Drilling fluids are used to aid the drilling process. Water based mud (WBM) and oil based mud (OBM), and 'sweeps' (sea water plus bentonite pills) are used as lubricants, and to reduce the levels of friction and heat during drilling. These materials also help bring sand and rock ("cuttings") from the well to the surface and are used to control pressure in the well. In practice a combination of sea-water, sweeps, WBM and OBM are often used in drilling operations. Mud selection depends on a variety of factors including reservoir geology and lubricant rheology.

Drill cuttings emerge continually during drilling, consisting of rock, sand and particulate from the well. These are required to be separated from the drilling mud and disposed of. The main means of disposal for drill cuttings that are not contaminated with OBMs is returning them to the sea-bed (Ffyne, 2014, Ythan, 2014, and Mariner, 2012), using a caisson at sub-sea depth to release the material. There are provisions in much of the EU for handling of drill cuttings contaminated with oil-based mud and water-based mud[23], meaning that in much of the EU, these are either treated offshore or shipped ashore for treatment/disposal. Any drilling muds that cannot be reused in the drilling operation are consigned to sealed skips for return to shore as waste.

Cementing and casing is a key process that occurs during drilling to ensure that the integrity of the well is maintained. This process involves the insertion of steel casings into the drilled sections of well which are held in place by cement to ensure the well structure is robust and safe from leakage. Cement is pumped down into the casing as a slurry, with drill mud and sometimes gel strengthening agents (Kew, 2012). The pressure from the drill mud causes the slurry to spread out and reach the bottom of the well. Once the slurry has reached the bottom of the well it backtracks up around the casing filling any voids and then setting (OCD, 2010).

Well completion

Well completion involves the final preparation of the drilled well, which includes rinsing out the well, installation of valves, instruments and tools needed to facilitate and evaluate the production process as it occurs.

Well bore clean-up is required after well construction to remove any remaining drilling mud or cuttings from the well prior to production. The well is flushed with water and 'clean-up pills' which return any residual materials to the surface. This material is assessed for waste flows which are visibly oily and visibly clean, and any contaminated material dewatered and skipped to shore for disposal. Water produced from this process is typically cycled through the well until it is visibly clean. This material is then typically sampled and analysed for oil content in order to be returned back to sea. As per the requirements of the OSPAR Convention (OSPAR, 2014), the performance standard for oil in discharged produced water is 30 mg/l calculated as a monthly average; under HELCOM the requirement is 15 mg/l (40 mg/l where not achievable through BAT/BEP); and under the Barcelona Convention the standard is 40 mg/l (monthly average, with an absolute maximum of 100 mg/l).

Introduction of completion fluid is the final step in preparing the well before production can begin. Completion fluid is made up of a variety of chemicals designed to protect the integrity of the well. In particular, these chemicals include corrosion inhibitors, biocides and oxygen scavengers. The exact composition of the completion fluid used varies, but may include sodium, calcium and potassium chlorides (Ffyne, 2014 and Mariner, 2012). As with other produced chemicals from the well the completion fluid is typically collected and retained for dewatering and return to shore as waste.

Exploration drilling may not involve all of the stages outlined above, depending on the success or otherwise of the well. Unsuccessful wells (i.e. those without recoverable hydrocarbons) are abandoned, while successful wells may be taken to various stages

[23] For example, under HELCOM Annex VI (covering the Baltic Sea), discharge of OBM-contaminated cuttings is prohibited and they must be taken ashore for treatment/disposal, while WBM-contaminated cuttings is subject to authorisation by the competent authority, to ensure that they are of low toxicity (e.g. Hg and Cd content < 1 mg/kg and EC50 >10,000 mg/kg in marine biota). Likewise in the OSPAR region, Decision 2000/3 prohibits discharge of cuttings contaminated with organic phase fluids > 1% dry weight (it is understood that this has had a de-facto effect of ceasing discharge of OBM-contaminated fluids in the OSPAR region). By contrast, under the Barcelona Convention, OBM-contaminated cuttings must have oil content <10%. No such limits have been identified under the Bucharest Convention. (These conventions cover the majority of the main EU sea areas).

of completion before being plugged and marked for return as part of field development for production.

2.4.2.4 Stage 3 – Production

Facility Design, Planning and Construction

Field development begins with design and planning activities (Engineering, Procurement and Construction (EPC)) which may last several years depending on the scale and type of proposed offshore installation. A wide variety of different installations may be used to access offshore resources, depending on the nature of the site, type and quantities of hydrocarbons and variation in reservoir conditions. The most optimal requirements and use of particular equipment are typically determined during what are termed Conceptual, Front End and Detailed stages of design and engineering. In all cases, offshore facilities are designed and built onshore, before being mobilised to site for installation, hook-up and commissioning.

Installation of Platforms and Subsea Equipment

Selection of platforms for use in an offshore context is largely determined by the type and nature of reservoir, production requirements and conditions at the site. Offshore facilities may be installed as entirely new build developments (‘greenfield’) or as upgrades to existing facilities (‘brownfield’).

Some examples of common platform types include:

- Shallow water complex (used in depths of <100 metres). This type of platform makes use of multiple independent platforms with different functions (such as processing platform, accommodation, and power generation) joined together with gangways between platforms (EEP, 2015);
- Gravity base (used in depths of 100 – 500 metres). A gravity base platform uses a central concrete column attached to the seabed, often with oil storage inside the central column. The platform at sea level will include all production units (processing, accommodation, energy generation) within one structure (EEP, 2015);
- Compliant towers (used in depths of 500 – 1000 metres). Compliant towers are similar to fixed platforms like the gravity base with a narrow tower attached to the seabed. The main difference between gravity base and compliant towers, is that the latter has more flexibility which allows them to operate in deeper water, where greater pressure from wind and sea would be exerted upon the structure (EEP, 2015); and
- Floating production (used in depths of 200 – 2000 metres). Floating production units typically make use of a tanker type hull with floating vessel attached to sub-sea wells. Floating vessels have greater flexibility than fixed structures but require support to be held in place, either via chained connections to the sea-bed or through dynamic position thrusters (EEP, 2015). In practice floating structures can take on a number of roles which span:
    - Floating storage and offloading (FSO) – no on-board processing unit;
    - Floating production, storage and offloading (FPSO);
    - Floating drilling and production, storage and offloading (FDPSO); and
    - Floating storage regasification units (FSRU).

Alternatives to tanker hull based floating platforms including tension leg platforms (TLPs) and spar platforms. TLPs make use of a vertical structure using hollow tendons secured to the sea-bed to support the platform in place. Spar platforms consist of a single hollow floating cylinder which is tethered to the sea-bed, but does not extend all the way to the sea floor. The width of the cylinder helps stabilise the structure and prevents it from tipping over. The operational platform is then placed on top of the cylindrical column (EEP, 2015).

Example diagrams of shallow water complexes, gravity bases, compliant towers, FPSOs, tension leg platforms and spar platforms are provided in Figure 2.13 – Figure 2.18.

Figure 2.13: Shallow water complex

Figure 2.14: Gravity base

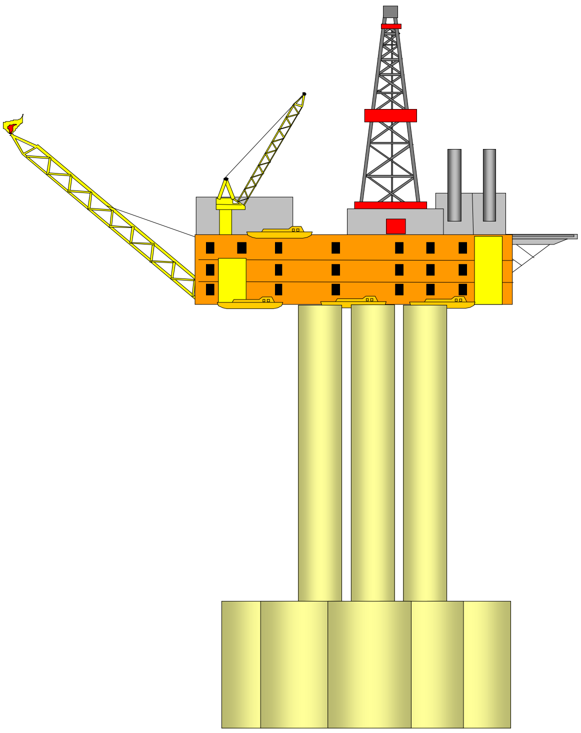


Figure 2.15: Compliant tower

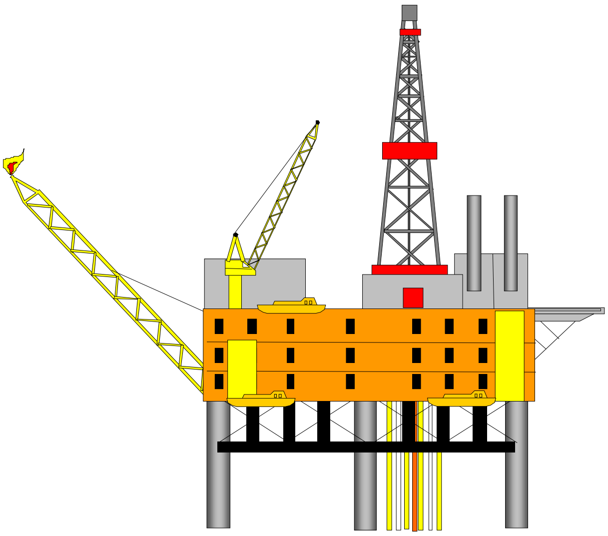


Figure 2.16: FPSO

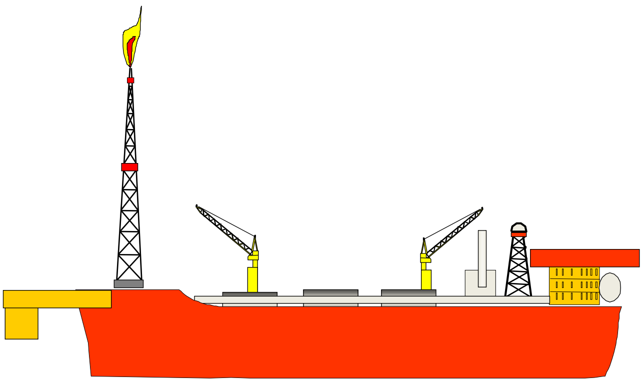


Figure 2.17: Tension Leg Platform

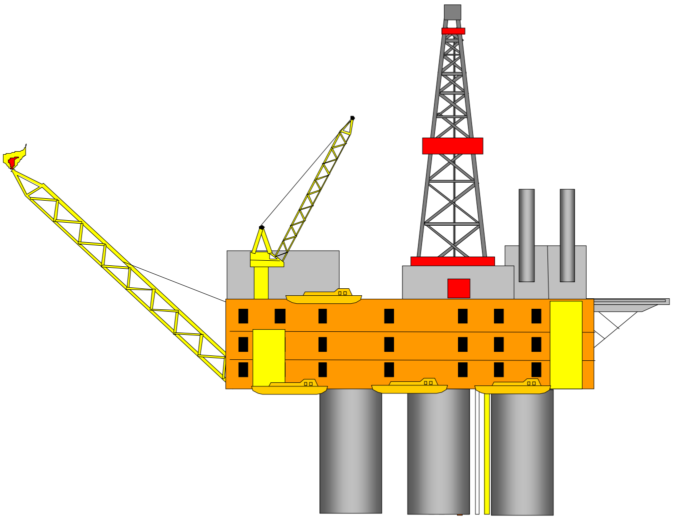
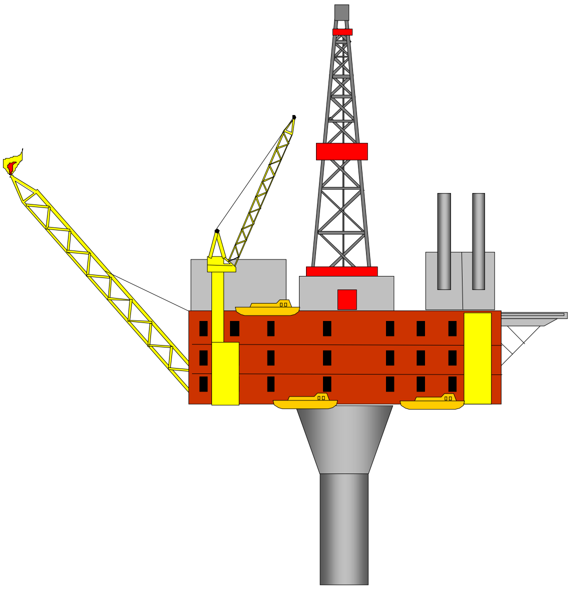


Figure 2.18: Spar Platform



Fixed platform structures require installation of a rigid structural 'jacket' onto the seabed, which connects the topsides and holds the platform in place. Floating installations make use of a combination of tethering, anchoring, or dynamic positioning systems to achieve a stable position. A number of seabed stabilisation processes may be used depending on the environment and platform type, including:

i) Pilling;
ii) Gravity based rigs;
iii) Suction cans / spud cans;
iv) Rock dumping; and
v) Tethering.

Piling is a process whereby a fixed concrete baseplate is installed on the seabed and held in place by pins drilled into the seabed. An example of the piling structure used within the Ffyne oil field (Ffyne, 2014) is shown in Figure 2.19.

Gravity based rigs are structures with concrete based foundations which can be up to 50 metres in width and which are held in place on the seabed by the weight of the structure.

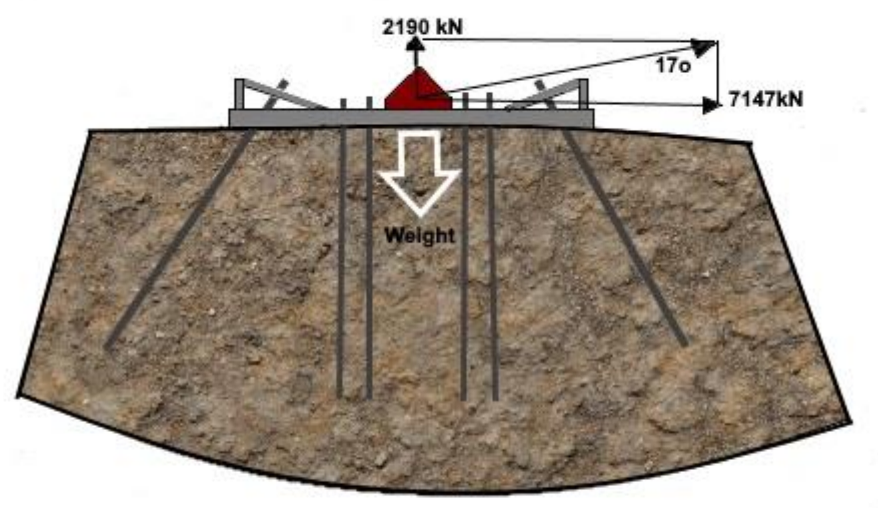
Suction cans (also known as spud cans), are used by jack-up rigs (Ffyne, 2014 and Kew, 2012) and are attached to the "feet" of the tower structure to hold the structure in place on the seabed. The structure is prevented from sinking into the soft sea-bed by displacing the weight of the structure across a wide area, as the cans are typically 8 – 18 metres in diameter.

Tethering may also be used to hold the structure in place with guide-chains. These have a high tensile strength and brace the structure against sea movement effects, with the tethers themselves being fixed to the seabed. Where semi-submersible vessels are used, pontoons and ballast tanks are used to counter the effects of waves on the motion of the vessel, with tethering/anchoring to further hold the vessel in place.

Rock dumping is another option used to weight apparatus into place. The use of rock dumping can be used as a complementary option with suction cans to ensure that the structure is fixed into position.

All of the technical options described within the above may also require the use of support vessels to help manage the process and enforce exclusion zones during the operations of the platform.

Figure 2.19: Example of micro-piling approach to installation of drilling rig



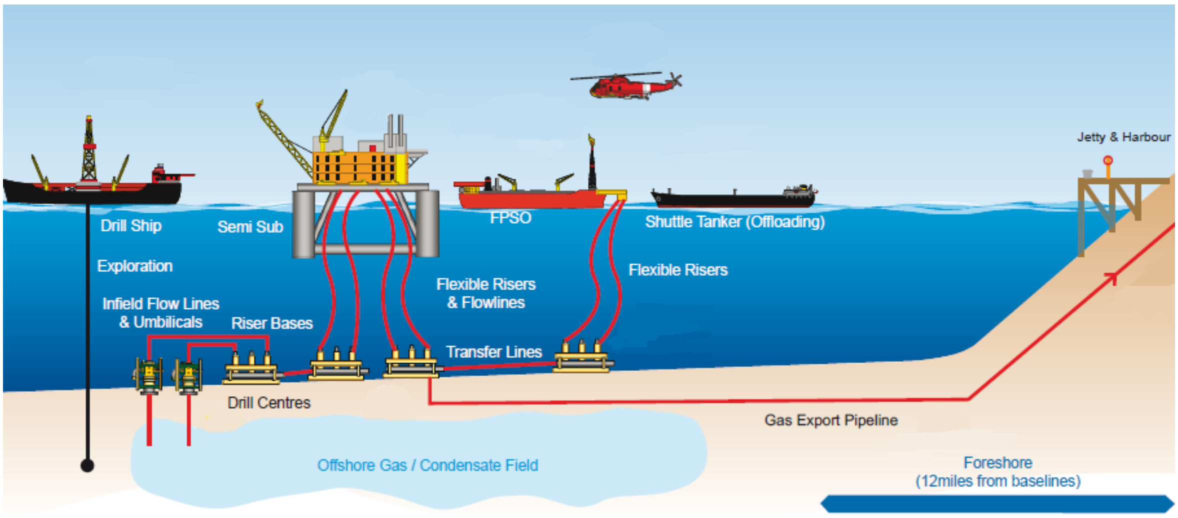
Based on Reference Ffyne environmental statement, 2014

Subsea infrastructure covers equipment located on the seafloor including wellheads, pumps, manifolds and pipelines. The following may be required to install and stabilise this infrastructure:

- Rock dumping – May be used to secure pipelines in place depending on the underlying seabed terrain;
- Trenching – An alternative to rock dumping involving digging a trench for the pipeline to sit in, which may also be back-filled; and
- Concrete mattresses – Concrete structures used to hold pipelines in place and to set distances between several pipelines, preventing them from rubbing or overlapping.

Figure 2.20 provides an example of a generic sub-sea network.

Figure 2.20: Example of subsea network for offshore oil and gas installations



Pre-commissioning includes all activities required on the platform topsides to begin production. Within the well this includes pressure testing using either gas (nitrogen, helium, or air) or water to test the overall integrity of the apparatus. As part of pre-commissioning it may also be necessary to carry out a 'water injection' process to initiate the flow of oil and gas in a well (OCD 2010). Multiple water injection wells are sometimes used to maintain pressure within the field and force hydrocarbons towards the main borehole (Fyne, 2014, Ythan, 2014 and Mariner, 2012). The use of water injection wells also allows the re-injection of produced water from wells.

Platform operations

Offshore installations are complex structures carrying out concurrent activities to achieve production from a variety of different infrastructure. For the purposes of this overview, this infrastructure is broadly classified into the following categories:

- Production processes;
- Topsides utilities; and
- Export facilities.

Production processes

Chemical injection is required at periodic stages to maintain the continuity of the well-bore and prevent damage from corrosion, biological, or chemical attack of the production infrastructure. This is a similar process to chemical injection used for enhanced recovery. However, in enhanced recovery, chemicals are employed to alter the properties of the formation in order to increase production, rather than improve the integrity and reliability of the well. Chemicals including methanol and corrosion inhibitors may be used to maintain well integrity (Kew, 2012 Ythan, 2014 Peterhead, 2014 Mariner, 2012, Edradour, 2012 and Ffyne, 2014). For gas fields there is also the use of active hydrate control injection to stop flow lines blocking up at low temperatures; this includes the use of for example monoethylene glycol (MEG).

Subsea production systems includes all infrastructure that are below the installation topsides, and located at sea level. The exact differentiation between what constitutes subsea and topsides is a matter that is specific to individual installations, but normally the subsea component begins with any pipework or structures that are below the level of the lowest deck of a platform (or hull in the case of vessels) and connect the topsides to infrastructure at seabed level. This includes all valve assemblies, pumping equipment at subsea and tie-backs to existing networks which are used to inject materials into wells or for retrieval of production back to the topside facilities for further processing.

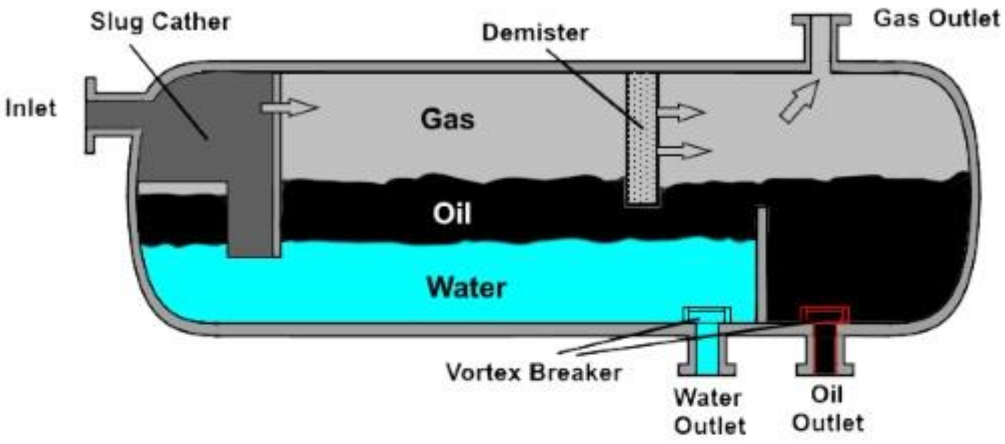
Topsides facilities are responsible for the production, processing, storage and export of reservoir fluids comprising a mixture of hydrocarbons, formation-water, reservoir contaminants and sand in varying ratios, depending on the geology of the specific site and whether the main product is oil or gas. The following sections provide an overview of the key equipment and activities on topsides.

Oil processing and handling requires a set of techniques to separate oil, water and gas as well as the removal of undesirable sand and mud.

Separation techniques use a series of settling tanks under different levels of pressure and temperature to force the oil, water and gas to partition. Primary separation allows water and oil to partition into discrete fractions for production as shown in Figure 2.21. Retention time within a settling tank allows gas to bubble out of the water component (Devold, 2013). Typical conditions for primary separation are pressure at around 30-50 times ambient (3-5 MPa) and temperature around 100 – 150 degrees Celsius (Devold, 2013). Produced water recovered from the separator is contaminated with oil and requires further processing, as discussed under 'produced water management' (Section 3.5.2).

Secondary separation is similar to primary but with reduced pressures and temperatures.

Figure 2.21: Separation tank for processing of oil and water



Based on Reference Devold, 2013

Following separation, fluids may enter a coalescer, a tank which holds only liquid fractions and uses internal electrodes to break the chemical bonds between water and oil to remove any final trace quantities of water.

Processed gas is either stored for export; exported directly through an export pipeline; or in some cases smaller quantities may be flared off the installation.

Processed oil can either be stored as cargo on the installation, transferred to a floating storage and offloading facility (FSO) or exported via pipeline.

Gas processing and handling covers both the gas component recovered from oil production, but also gas recovery from gas fields. In the latter case production of gas will be made up of a combination of gas, condensate (light hydrocarbon fraction) and potentially sand and debris from the well-bore. The key emphasis for these processes is on removing liquids from the gas and then dehydrating the gas. This process involves pressurised separation to remove condensate from gas. Desiccants can also be used to remove any water which condenses within the process tanks.

Finalised processed gas from gas fields is typically introduced under compression into pipeline networks for transmission back to onshore processing facilities.

Produced water management involves the recovery of water from separation and removing quantities of hydrocarbons before releasing it to sea or reinjecting it into the reservoir (Ythan, 2014 Peterhead, 2014 and Mariner, 2012). Typical treatment for produced water makes use of centrifugal equipment called hydrocyclones to further separate water and oil and reduce concentrations below acceptable levels (OSPAR, 2014). It may also be necessary to use a subsequent degassing stage to remove any final trace quantities of hydrocarbon gas.

Off-gas management (e.g. flaring) covers the management of gases captured during separation. Flaring activities are tightly controlled and usually require consents, which is the case in the UK (Energy Act 1976[24]), and Norway (Statoil, 2015). Flaring equipment typically incorporates a 'knock-out' drum to capture any liquids (e.g. condensate) in the gas stream prior to it reaching the flare.

Produced sand management is required if sand is recovered as part of the separation process. Sand contaminated with oil is typically cleaned to remove the oil fraction. The sand may then be returned to the sea, subject to permit (Devold, 2013) or retained within skips for return to shore. The management of sand as an issue in oil and gas production is typically mitigated at source through the use of techniques to reduce sand generation such as downhole gravel packs, and forward modelling and planning of geology before production begins.

Enhanced recovery (see 2.4.1.4): Although ER applications are mainly conducted onshore, technologies have developed to expand into offshore applications (Rigzone, 2015). The abundance of seawater results in relatively low costs for the water flooding processes offshore, although filtering, deoxygenation and biociding are generally required. In some cases it may also be economical to re-inject produced water for water flooding. The development of tertiary ER for offshore faces particular challenges: working at sea including the cost of development, the weight, space and energy consumption requirements of retrofitting existing offshore facilities and fewer wells that are more widely spaced contributing to displacement, sweep (Oil and gas glossary, 2014)[25] and lag time. Although there are still challenges, the application of tertiary ER is currently being considered or has moved forward for a number of offshore developments (Rigzone, 2015). The only ER processes considered to be mature for offshore activities are water flooding and miscible gas injection using hydrocarbon gas, because produced gas often cannot be stored or utilised economically (Alvardo et al, 2010). Therefore, these are the only processes for which risks and impacts are considered under the 'enhanced recovery' sub-stage for offshore activities.

Well stimulation (low volume hydraulic fracturing) (see 2.4.1.4): Low volume HF has been in commercial use as a well stimulation method offshore since the 1990s. However, it remains limited compared to the onshore industry, making up just 5% of the global hydraulic fracturing market (Betts, 2014). It is not clear to what extent low volume hydraulic fracturing is currently applied in offshore conventional wells in Europe, or how its usage is likely to change in the near future. In March 2016, several Member States indicated to the Commission that enhanced recovery techniques (steam injection, water flooding and gas injection) were occasionally used in their conventional oil and gas fields. There were also reported cases of low volume hydraulic fracturing in conventional oil and gas extraction; however, it was not specified whether this occurred onshore or offshore.

Topsides utilities

Power generation and combustion equipment is used to provide an energy source to the installation during production. This normally occurs via either turbines or large reciprocating diesel engines. Turbines may run on diesel or gas and may utilise produced gas from the separation process (Mariner, 2012 and Ffyne, 2014).

Hydrocarbon and chemical storage covers all materials stored upon the platform for use in production, as well as the storage of produced hydrocarbons. Offshore installations typically store large quantities of diesel to fuel energy generation systems. A variety of chemicals may also be stored for use in well operations during production. Materials such as these are held in designated storage areas with

[24] DECC, 1976 Energy act – consents for flaring https://www.gov.uk/oil-and-gas-fields-and-field-development

[25] In the reservoir a sweep is displacement of a hydrocarbon fluid from a reservoir rock by a flooding fluid. http://oilgasglossary.com/sweep.html

protection and capture systems, such as bunding and drainage systems. Other fuels, such as aviation fuel for helicopters, are also stored throughout the installation in smaller quantities.

Diesel and chemical deliveries/loading are a standard part of the general running of an installation during production. Transfers are primarily performed as bulk transfer operations, either by loading hose or in tote tanks.

Open loop sea-water cooling systems maintain the temperature of processing and other equipment, such as turbines for power generation, and separation and coalescence tanks which operate at different temperatures and pressures.

Heat, ventilation and air conditioning (HVAC) systems are used to provide conditioned air to equipment and personnel working areas and accommodation (Devold, 2013).

Drainage systems offshore are used to capture any spillage / lost material, including diesel, oil or chemicals. Different drainage systems are used on board the installation depending on their location and service. For drainage systems located around process equipment and machinery spaces, these systems are connected to bilge tanks where further separation of oil from water based materials is carried out (Mariner, 2012 Ffyne, 2014 and Kew, 2012). Recovered oil from the bilge tank can either be returned to processing or stored as waste for return to shore dependent on the quality of the oil (Mariner, 2012 and Ffyne, 2014). Open drains located on deck areas are used to capture lost material which is then held within open drain tanks, sometimes separated into hazardous and non-hazardous, with material treated prior to discharge overboard.

Waste Management covers all waste materials that are generated offshore and include:

- Generation of solid non-hazardous wastes such as WBM-contaminated drill cuttings;
- Generation of solid high hazard wastes which require further processing such as OBMs and untreated cuttings;
- Generation of liquid low hazard wastes such as grey water and sewage; and
- Generation of liquid high hazard wastes which require further processing such as oil contaminated water.

Management of the wastes produced depends on the nature of the waste and its origin and destination. For those wastes generated as a result of processing oil and gas, defined closed system processes are used to further treat and manage final disposal of waste.

For liquid wastes created from the accommodation block such as grey water (from washing, showers, rainwater), black water (sewage) and food waste, discharge is permitted provided these materials are treated and managed in accordance with the requirements of MARPOL (Ythan, 2014 Kew, 2012 Ffyne, 2014 and Mariner, 2012).

Solid wastes, particularly OBMs and cuttings, are typically held within sealed skips for return to shore and further processing. Developing technologies have begun to remove the need for returning to shore through the use of thermal treatment to drive off the oil and allow treated cuttings to be returned to the environment. See also the commentary elsewhere on the different requirements for such cuttings in different sea areas.

Other non-hazardous solid wastes such as scrap metal, packaging and office waste are held within sealed skips for return to shore and further processing.

Export facilities

Export refers to the transfer of hydrocarbons away from the offshore installation, typically either by vessel or fixed pipeline.

Export by vessel occurs in the form of hydrocarbon offtakes, whereby the product (typically oil) is transferred to shuttle tankers for return to shore and onward processing. In this case, the passing tanker hooks up its cargo tanks to the installation via a loading hose, and oil is pumped from the installation's holding tanks to receiving tanks on the shuttle tanker over the course of several hours.

Export by pipeline involves the transfer of hydrocarbons from the installation via a dedicated export pipeline to either the shore, another nearby pipeline, or a neighbouring facility. The latter case is known as a tieback. It is possible to make use of comingled pipelines which carry both oil and gas without physical separation; while gas only pipelines are also used with a more narrow gauge than oil and gas pipelines (OCD 2010). In both cases oil and gas are introduced into pipeline networks under pressure.

The use of transmission pipelines for oil and gas requires continual maintenance to ensure optimal function, including the removal of deposits which can build-up. Pipelines are maintained using a process called 'pigging' where a mechanical device known as a pig is sent along the line to clean it (Devold, 2013).

2.4.2.5 Stage 4 – Project cessation and well closure

Overview

Life-cycle stage 4 covers the cessation of production from a given well and well closure; the full removal and abandonment of equipment from the site has been detailed within life-cycle stage 5. The reason for this separation is that a given installation offshore can service multiple wells over the course of a production life-time, with wells independently closed as required. This section therefore covers those activities specific to ceasing production on a per-well basis.

Typically life-cycle stage 4 begins with a planning phase and development of a decommissioning programme which should be agreed with the competent authority depending on where the oil and gas field is located. Additional planning measures will include an environmental impact assessment (which covers life-cycle stage 4 and 5) and if necessary survey of the seabed area dependent on what recent data is held by the operator.

Well closure

The well closure and cessation phase of life cycle 4 will cover the following activities and processes:

- Preparation for well plugging;
- Well plugging and conductor recovery; and
- Pressure testing and cessation.

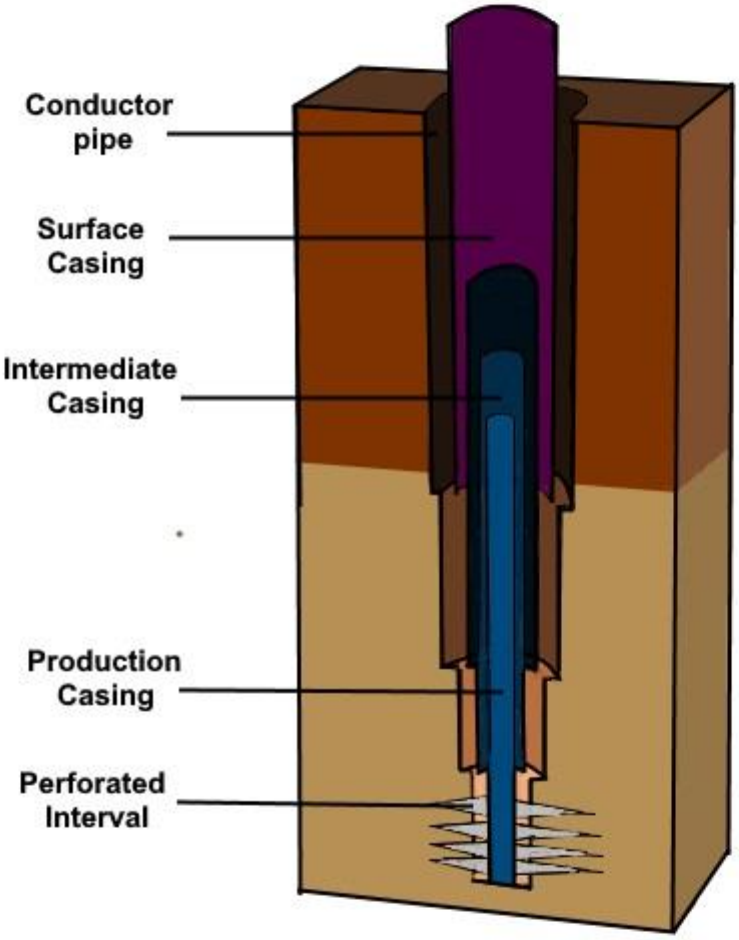
Preparation for well plugging covers the mobilisation of equipment needed to carry-out the plugging operation. This can include setting up equipment on the seabed to assist in removing 'in-well' equipment and delivery of plugs. The process can involve the use of slick line units to manage the movement of equipment to and from the well prior to plugging. Care is also required during this operation to manage the integrity of the well and well-head and internal pressures within the well.

Well plugging typically involves the use of 'cement' plugs at multiple points within the well to prevent the loss of any residual hydrocarbons to the sea. Sea water is used to flood the well and maintain a standard level of pressure within the well equal to the surrounding conditions between plugging points. The number and type of plugs per well will vary dependent on the depth of the well and the surrounding geology at the site. Each plug will be tagged and carry required equipment to monitor and pressure test the integrity of the well below each plug point.

Conductor recovery refers to the first tier of steel casing that is inserted into the well. The conductor casing (illustration shown in Figure 2.22) performs an important job within the well as the interface between the seabed surface and the lower tiers of well casing. The conductor casing is typically the widest gauge of the steel casings inserted into the well and with stands the greatest pressures which also includes a proportion of the well casing above the level of the seabed connected to the well head and blow-out preventers. Under IMO regulations (Rigzone, 2015) the conductor casings must be removed to a minimum of 15 feet below the sea floor. Where casings are cemented into place to ensure the robust integrity of the well during production, conductor recovery is an intense process which can require:

- Severing of the conductor from the surrounding structures using abrasive cutting tools or if necessary explosives;
- Pulling and twisting operations to remove the casing from the well;
- Sectioning of the casing which involves cutting the casing down to manageable lengths depending on the original length of conductor used; and
- Removal of the casing for return back to the topside facilities for on board management and return to shore.

Figure 2.22: Conductor casing for oil and gas wells



Based on Reference: www.rigzone.com

Pressure testing and cessation is required after each stage of plugging but also with the recovery of the conductor and final plugging to ensure the integrity of the now closed well. Locations of abandoned wells are recorded and provided to the competent authorities depending on the specific location of the well site. Monitoring activities for post-closure are detailed further within life-cycle stage 5.

Management of cuttings pile

During drilling, cuttings can be discharged to the seabed, re-injected into a well or taken ashore for treatment and disposal with the choice of disposal route influenced by type of drilling mud used and the location of the well. Drilling muds can be oil based mud (OBM) or water based mud (WBM). OBM contaminated cuttings do not disperse readily when discharged, which has historically resulted in accumulations of cuttings piles and OBM beneath installations. WBM readily disperse and therefore cuttings piles are not generally formed. As described in Section 2.4.2.2 above, there are various requirements for avoidance or treatment of contaminated drill cuttings in different parts of the EU.

By way of example, for the OSPAR region, OSPAR Recommendation 2006/5 on a Management Regime for Offshore Cuttings Piles sets out the management regime for offshore cuttings piles, with the purpose of reducing the impacts of pollution by oil and other substances within the pile to a level that is not significant. The management regime comprises two stages:

Stage 1 - a screening process to determine if the pile requires further investigation based on the following two thresholds set out in the Recommendation:

- Rate of oil loss to the water column: 10 tonnes /yr; and
- Persistence over the area of seabed contaminated: 500 km^2yr.

Where a cuttings pile falls below both of these thresholds and no other discharges have contaminated the cuttings pile, no further action is required, this is the leave in-situ option. If either of the thresholds is exceeded, however, the Stage 2 assessment must be initiated.

Stage 2 - requires that a comparative assessment be conducted to determine the Best Available Techniques (BAT) for the management of the cuttings pile which should include the following options:

- Onshore treatment and reuse;
- Onshore treatment and disposal;
- Offshore injection;
- Bioremediation in situ;
- Covering in situ; and
- Natural degradation in situ.

The Recommendation required that all piles were screened by 30 June 2008. Each option has it positive and negative effects for managing piles and is partly governed by the residual quantities of hydrocarbons released to sea with thresholds set out within the OSPAR recommendation.

2.4.2.6 Stage 5 – Post closure and abandonment

The final life-cycle stage includes the removal and (where possible) recycling of topside structures from the oil and gas field, management of seabed structures such as pipelines and return of the site back to nature. In practice the decommissioning of the offshore installation represents a significant engineering challenge to safely deconstruct and remove the apparatus installed during the well construction and production phases. As with lifecycle stage 4 this process begins with planning phases and development of a decommissioning plan describing the measures the operator proposes to take in connection with the decommissioning of the installation(s) or pipeline(s) listed. This is supported by an environmental impact assessment to evaluate the impact of all decommissioning activities at the offshore location and also at the onshore dismantling and disposal site. These stages would also typically be carried out in conjunction with discussions involving the competent authority and granting of permits to proceed which will vary depending on the specific location of the installation and national competent authority body.

The decommissioning process can broadly be broken down into three stages, with a fourth stage 'shipping' likely occurring at all of the three preceding stages in this life-cycle stage:

- Decommissioning of the topside structures in preparation for removal;
- Jacket dismantling and removal of structures fixing installations to seabed to allow removal;
- Management of pipeline and bundle assemblies where in place; and

- Shipping – occurs at all prior stages.

Topside decommissioning typically includes:

- Accommodation and helideck;
- Drilling derrick and support;
- Utilities - firewater and safety systems, water purifying equipment, chemical storage and pumping, potable water bulk storage and pumping, hot water boilers, electrical switchboards, workshop facilities, and diesel fuel storage and pumping;
- Oil and Gas production process modules;
- Water injection module;
- Power generation modules;
- Wellhead modules;
- Flare tower; and
- Drainage systems.

Prior to removal, the topsides must first be prepared in line with environmental and safety considerations. The 'making safe' of both facilities and pipelines includes cleaning, draining, engineering and waste management. Thereafter, the topsides, process and utilities modules are separated and appropriate engineering, such as the installation of lift points, can take place to enable removal.

Removal encompasses the removal of topsides, substructures and subsea infrastructure. Prior to removal, detailed studies and engineering take place to support the structural separation and chosen removal method.

Topside removal can involve re-engineering and cutting of topside modules. Most commonly topside removal is achieved by the piece-small, reverse-installation or single-lift methods. Smaller substructures, can be removed in a single lift and transported onshore via barge or lift vessel. Larger substructures may require sectioning into manageable pieces and multiple removal lifts.

Jacket decommissioning refers to the legs which connect the topside platform to the seabed and will be fixed in place using steel and concrete materials. For decommissioning it is possible to remove the topside platform from the jacket and then to remove the jacket from the sea which typically leaves behind the footings and remaining structures. Again, given the size and weight of the jacket structure, the removal of these facilities represents a significant engineering challenge which can be approached in multiple different ways. However standard steps to decommissioning of the jacket include:

- The dismantling of the jacket structure, likely involving the use of cutting tools;
- Clean down of the jacket to remove any marine growth prior to decommissioning. This is intended to avoid the translocation of marine species to new areas where they might represent an invasive species;
- Management of the jacket structure itself which can involve removal as one piece, cutting into sections, or further cutting into smaller components to aid the ease of removal and return to shore; and
- Removal of base-components, which requires the uncovering of footings and pilings and abrasive cutting to remove the bulk of this structure.

For foundation phases which are left in-situ environmental impact assessments will be used to assess the risk posed by corrosion and release of metallic materials to the sea and potential risk posed by upright structures to other marine users such as fishing vessels.

Pipeline and bundle removal covers the remaining structures left on the seabed and in particular the oil and gas pipelines. As stated in earlier sections, a given oil and gas field can be made up of multiple wells which are connected by pipe networks called 'tie-backs'. These networks will also ultimately feed into a central pipeline which transmits oil and gas back to shore, sometimes via additional junction platforms. The quantity of pipeline involved with a particular operation can therefore vary depending on the size of the operation, number of wells and distance from shore. At the final life-cycle stage the options to manage pipelines which are assumed to include both tie-backs and longer reaches of pipeline include:

- Leave in-situ – assuming that the pipeline is sufficiently entrenched within the seabed so as not to pose an environmental risk;
- Partial removal – this can involve removing some of the ancillary support structures such as concrete mattresses but pipeline is left in place; and
- Full removal – removal of the pipeline likely following the reverse process for pipe-laying which involves a support vessel with spool to retrieve the pipeline from the seabed as one piece.

Each option presents its own practical issues and benefits depending on what is required. Leaving pipeline in situ is best suited to those pipe networks which are fully entrenched and unlikely to pose a risk to shipping. In some instances leaving pipe networks in place may require additional rock dumping to ensure that the pipe remains in place.

For partial removal of the seabed structures, valve assemblies and concrete mattresses can be removed back to the surface, but pipelines need to be suitably entrenched and may still require rock dumping to ensure that they are held in place without risk of rupture.

For full removal of pipelines the network needs to be fully uncovered and free to be collected by shipping vessel which will wind in the pipe from the seabed. This is the reverse operation of pipe-laying. In order to ensure that the pipework is fully uncovered all fixtures such as concrete mattresses and rocks need to be removed and the pipe needs to be free of trenching. Typically a jet pressure washer is used to remove any sediment from the surface of the pipe leaving it free to be removed from the seabed.

Shipping. One common element to all of the final lifecycle processes and technologies relates to shipping, which will be required to deliver and remove equipment and materials for each of the processes outlined. Shipping is a key theme for the entire offshore oil and gas process across all five life cycle stages. The nature of the shipping vessels, size, and frequency of planned trips will vary for different life-cycle stages and processes. Also note the importance of helicopter trips for personnel on and off the platform during the production phase. For the final life-cycle stage the level of work can form an intense period of activity with the vessels used to ferry topside platforms in particular being of significant size and fuel requirements. An example of such a towing exercise is provided within Figure 2.23.

Figure 2.23: Example of a shipping vessel used to transport platforms

Long-term integrity failure. Once abandoned and plugged, all wells carry some risk that the integrity of the well will be compromised over time. The chance of this occurring decreases when there are multiple layers of containment built into the well. Older wells with less containment features or wells that have not been decommissioned properly or orphaned may carry an increased risk of long-term failure. The location of the well also has a significant effect on the likelihood of containment failure, (Ingraffea et al, 2014) and there must be a negative pressure gradient in order for a leak to occur. This implies that abandoned wells may have a lower risk of containment failure than active wells, as their internal pressure may generally be lower than an active well. Evidence suggests that the probability of a leak from an active well is generally low (King & King, 2013), therefore it may be inferred that the likelihood of a leak from an abandoned well is also low, provided that it has been abandoned and sealed properly. According to industry (ConocoPhillips, 2013), once a modern well is properly decommissioned, the risk of long-term well integrity failure is extremely low.

3. Technological development and trends

3.1 Background

The exploration and production of oil and gas is a global business which has evolved significantly since its inception. The continuing advancement includes the development of new technologies and methods of exploration to reach more difficult to access resources. In addition to the environmental consequences of producing additional oil and gas from the ground, these technologies may introduce new environmental risks. However, some also have the potential to reduce the risk and burden to human health.

Currently, the oil and gas industry has reached a stage where conventional oil and gas reservoirs are starting to run dry and unconventional oil and gas reservoirs are sought. Maximising what resources are left requires new and emerging technologies.

Additionally, there is increasing pressure placed upon the oil and gas industry to demonstrate best practice in the field of oil and gas exploration, development and production. Previous incidents, such as Deepwater Horizon, have highlighted the need for thorough risk assessment and management to operators and regulators around the world. One of the actions taken following this incident was that IOGP created the Global Industry Response Group (GIRG) in July 2010 (IOGP, 2010b). GIRG divided its work into three core areas:

- Prevention: to improve drilling safety and reduce likelihood of a well incident;
- Intervention: to decrease the time it takes to stop the flow from an uncontrolled well; and
- Response: to deliver effective oil spill response preparedness and capability.

On-going and future research and development is key to ensuring that continued advances in new technologies incorporate further improvements to reducing environmental risks.

The development of new technologies will pass through a series of phases before it reaches a point of mass production and utilisation by the oil and gas industry. However, despite the thorough qualification required for technology, the industry is often able to complete this process quickly to develop new technology when there is an urgent demand. A good example of this is the development of well capping and containment equipment following the recognition of the potentially severe environmental damage caused by blowouts. Typically the technological developments on offer can be divided into two classes: firstly the 'unproven' emerging technologies which have reached prototype stage but which are still largely untested within commercial operations, and secondly the 'proven' emerging technologies where ingress into commercial use does occur but is still at an early stage where mass adoption of the technology in question has not yet occurred.

In developing this report the focus has been placed on those proven emerging technologies which are likely to be taken up more widely by industry in the short to medium term. The project terms of reference refers to "the next 5 years", and this is interpreted here as a broad indication of timescales, rather than a prediction of the extent of deployment of technologies within a specific timeframe.

3.2 Summary of selected technologies areas

Based on review of publically available industry publications, workshop and seminar documents and service company provided information, a short list of the most important emerging technology areas has been identified. It has been noted that much of the information gathered came from information exchange platforms such as innovative showcases rather than peer-reviewed or independent material. Expert judgement has then been applied from within the project team at Amec Foster Wheeler who work directly with the oil and gas industry, in order to refine this list further to focus on those proven emerging technologies with the greatest likelihood for widespread adoption by industry in the short to medium term.

The list of emerging technology areas identified include:

1. Discovery of new oil fields – increasing computing power is thought to contribute to increasing the world's conventional oil resource base;
2. Maximise recovery of resources from existing reservoirs – opportunities in the field of digital oil fields, nanotechnology and lightweight materials;
3. Reduction in exploration and production costs – finding economic viability from activities in more challenging environments;
4. Opportunities in the non-conventional heavy oil resources; and
5. Minimising environmental damage – to protect the environment and preserve natural ecosystems.

Whilst there are many emerging technologies in various areas, they are mostly influenced by objectives of enhancing cost effectiveness and maximising yields and to a lesser extent by changes in environmental or climate legislation. Seven main technological areas are selected and assessed in the follow section. The highlighted technological areas are:

- Emerging enhanced recovery techniques;
- Robotics;
- Seismic survey technologies;
- Floating LNG;
- Drilling technologies – coiled tubing;
- Emissions reduction technologies – D.L.E. ; and
- Nanotechnologies.

3.3 Emerging technologies

3.3.1 Emerging enhanced recovery techniques

3.3.1.1 Background

ER techniques have been continuously evolving with improved methods and technologies that have been developed over the years, with significant advancement seen in recent years. The chief challenges faced by adopting ER technologies are that they are expensive and resource intensive due to high injectant costs (Kokal et al, 2010). However ER does allow capture of significant oil reserves that would otherwise be unsustainable.

ER technologies are applied to older fields with falling oil production rates and where the recovery of oil and gas becomes harder and uneconomical to retrieve. New and advanced types of ER technologies are being pursued by manufacturers and operators to increase the recovery factor of reserves.

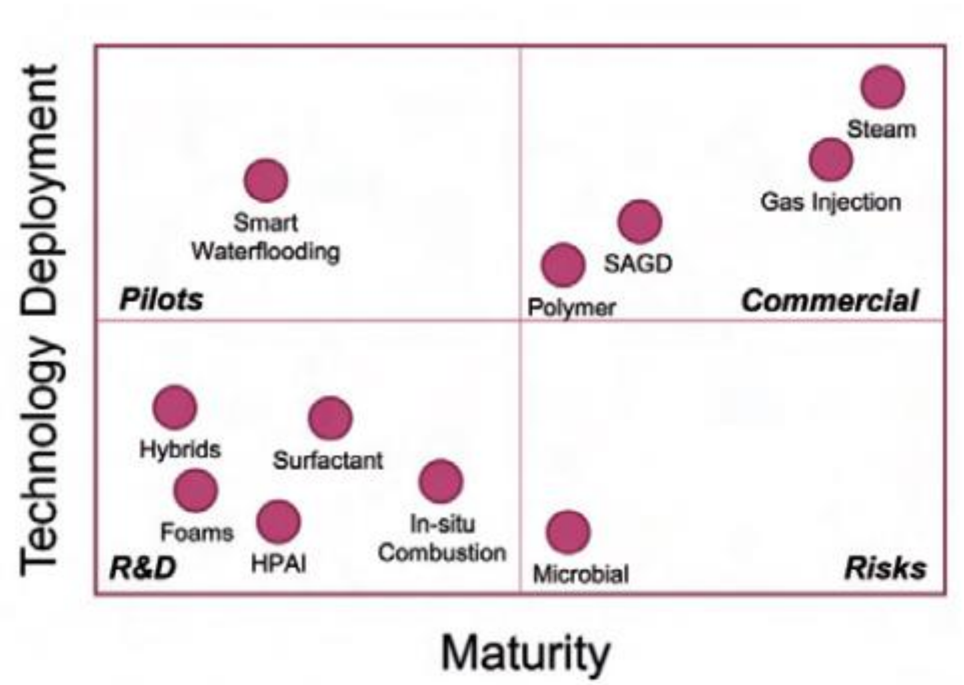
The global ER market was reported to be worth 38.1billion USD in 2012, and was at that point expected to grow to 516.7billion USD in 2023 (Offshore Engineer, 2014). Thermal, chemical and gas represented 51.5%, 10.2% and 38.3% of the global ER market respectively in 2012. The share of gas injection is expected to remain stable until 2023, while chemical is expected to increase to almost 30% by 2023 and thermal to fall accordingly.

North America dominated the global market in 2012, with over 38.9% market share in terms of volume. Europe is expected to exhibit a high growth rate, with global market share predicted to rise from 9.5% to 13.1% between 2013 and 2023 (Offshore Engineer, 2014).

3.3.1.2 Applications

Enhanced recovery technology was reported to have evolved from environmental concerns where there were incentives to sequester CO_2 (Kokal et al, 2010). There are now three major categories of ER reported to have been found to be commercially successful to varying degrees. These methods are grouped according to types such as reduction of oil viscosity, production of oil with a solvent and the alternation of capillary and viscous forces between the oil, injected fluid and the rock surface. Therefore the classified ER methods are thermal recovery, gas injection and chemical injection. Each have different competing methods. The figure below outlines the various emerging ER technologies (Kokal et al, 2010).

Figure 3.1: Technological development of different forms of ER



Reference: http://www.world-petroleum.org/docs/docs/publications/2010yearbook/P64-69_Kokal-Al_Kaabi.pdf

The most popular EOR methods are thermal (steam) and miscible gas injection which are currently considered as mature technologies. Newer and emerging technologies include acid gas injection, in-situ combustion (e.g. High Pressure Air Injection, HPAI for light oil recovery (Chen et al, 2013) and combination chemical flooding. Microbial, hybrid and other EOR technologies are currently at the research and development stage (Kokal et al, 2010).

3.3.1.3 Case studies of Enhanced Oil Recovery technologies

Specific examples of advanced EOR technology applications that have emerged are outlined below:

LoSal® EOR (Enhanced Oil Recovery) Process

The BP LoSal® EOR technology is used to flood or push more oil from reservoirs, therefore cost effectively recovering more oil over the lifetime of an oil field. Referred to as water-flooding, this technology is based on taking a new approach of using the low salinity water in oil reservoirs. Injecting fresh water into a reservoir causes problems as water can make the clays swell and block the pores that hold the oil. However by reducing the salinity of the water, it was observed that there was some pore-scale displacement, and increased recovery. The technology has been tested by BP and applied in an oil field in Alaska. Following the use of these applications, the technology will be applied to BP's Clair Ridge field (west of Shetland, UK) development plan.

Understanding that oil molecules are bound to clay particles by 'bridges' of divalent (double-charged) ions, the high salinity water of the reservoir causes the bridges to be compressed to the clay surface. Reducing the salinity encouraged these 'bridges' to relax, giving non-bridging monovalent ions access, allowing replacement with divalent ions. This chemical process removes the 'bridges' that help bind the oil to the surface of the clay particles. Once the chemical bridges have been removed the oil held within the reservoir can be freed (BP Magazine, 2014).

Designer Gas® technologies

Again, applied to various BP oil and gas fields, this technique was developed using natural gas that is produced along with oil, and cooled to -40°C. This produces two types of gas called lean gas and miscible gas.

- Lean gas is mostly methane, and it vaporises any "relic oil" (isolated groups of oil (BP Magazine, 2013) in the gas cap, displacing it from the rock; and
- Miscible gas consists of propane, butane and ethane and is injected into the main oil-bearing part of the reservoir. Miscible gas displaces 95% of the oil from the rock but is less effective than water for accessing or sweeping the reservoir. The miscible gas will need to alternate with water injection to improve sweeping resulting in a further increase of oil recovery.

This technique is also being applied offshore where BP operates the world's largest hydrocarbon gas injection projects using vaporisation and miscible gas at Prudhoe Bay in Alaska. These play a significant role in driving the expected oil recovery factor to around 60%. More than 40% of the production from Magnus field in the North Sea is sustained by miscible gas EOR. The production rate from the Magnus field was estimated to be 12Mbbl per day by Shepherd (2015), compared to 14MMbbl per day total in the EU (Statistica, 2014). In the Ula field in the Norwegian North Sea the current oil production is sustained almost entirely by EOR (BP, 2015). The overall extent of use across the EU is not known.

Statoil and Aker solutions – subsea gas compression (Aker solutions, 2013)

Similar to oil field recovery, gas fields can also require a boosting of the reservoir flow as pressure depletes over time. To resolve this issue, the solution has been to install gas compressors on an existing platform or to build a new manned compression platform. Subsea gas compression removes the need for an offshore platform or onshore compression facility. This means less infrastructure needs to be constructed and thus minimises environmental impact from transport of equipment to site. It is also a more cost-effective development, again due to the reduced shipping needs but also because of reduced operational costs during the lifetime of the development. The compressor can be situated close to the well and with lower energy consumption, emissions are reduced and there is a reduced human risk as operation is unmanned (OneSubsea, 2015).

However, like other subsea installations, some form of environmental impact would be potentially possible. Infrastructure installation, including drilling for anchoring and placement of the installation would potentially impact the seabed and biota of the marine ecosystems that live on and in the surface layer of the seabed, this could include loss of species from habitat displacement. Some marine colonies in the vicinity may be smothered or clogged by seabed disturbance and potentially new species could be introduced if rock dump materials were used, depending on sourcing of materials and quarantine procedures for invasive species (Edradour, 2012).

This type of technology will be deployed as part of the Asgard subsea gas compression project in 2015 and will be the first of its kind should it prove successful. This would result in the recovery of an additional 280 million BOE of gas and condensate, increasing reservoir recovery rates by 15-20%. This increase is reported to be equivalent to developing a new medium sized gas field offshore in the Norwegian Sea and also replaces the need for a submersible compression platform weighing around 30,000 tonnes, which is stated to be five times the weight of the subsea facility (Aker Solutions, 2012).

Next Generation CO_2 Enhanced Oil Recovery

In 2010, the U.S. Department of Energy moved into researching new CO_2-EOR techniques that would attract market interest. This was due to the (then) rising price of oil, combined with the availability of inexpensive CO_2 from natural sources in the US. CO_2 injections are already in use to a limited extent in many U.S. states such as the Permian Basin of West Texas and eastern New Mexico, Kansas, Mississippi, Wyoming, Oklahoma, Colorado, Utah, Montana, Alaska, and Pennsylvania. The focus of the new CO_2-EOR technology is to utilise CO_2 from industrial sectors such as natural gas processing, fertiliser, ethanol and hydrogen plants. The CO_2 can then be used to inject into the field thereby prolonging the life of the well and recovering more oil as a result. The research also explores techniques that can improve economic performance and expand the capability to other and broader types of reservoirs. This can include injection of larger volumes of CO_2, innovative flood design to deliver CO_2 to unreached areas of the reservoir and improve mobility control of the injected CO_2. The pressure of the CO_2 injection must be higher than the minimum miscible pressure (MMP). The American Petroleum Institute (2007) quotes an example pressure of 1400PSI for a CO_2 flood.

The list of projects that were developed included four for developing mobility control of the injected CO_2 with the use of foams and gels. This would encourage CO_2 to sweep through less permeable and unproductive areas of the reservoir. Another option investigated was the potential for oil production by CO_2 injection into the residual oil zone and this included two projects that were to develop simulation and modelling tools for CO_2-EOR. Links and project names are as listed:

- Improved Mobility Control in CO_2 Enhanced Oil Recovery using SPI Gels (Impact Technologies, LLC) (NETL, 2012);
- Engineered Nanoparticle-Stabilized CO_2 Foams to Improve Volumetric Sweep of CO2 EOR Processes (U. Texas - Austin) (NETL, 2015(a));
- Novel CO_2 Foam Concepts and Injection Schemes for Improving CO_2 Sweep Efficiency in Sandstone and Carbonate Hydrocarbon Formations (U. Texas - Austin) (NETL, 2014);
- Nanoparticle-Stabilized CO_2 Foam for CO_2-EOR Application (New Mexico Institute of Mining and Technology) (NETL, 2015(b));

- "Next Generation" CO_2-EOR Technologies To Optimize The Residual Oil Zone CO_2 Flood At The Goldsmith Landreth Unit, Ector County, Texas (U. Texas – Permian Basin) (NETL, 2015(c));
- Real Time Semi-Autonomous Geophysical Data Acquisition and Processing System to Monitor Flood Performance (Sky Research, Inc.) (NETL, 2015(d)); and
- CO_2-EOR and Sequestration Planning Software (NITEC LLC) (NETL, 2013).

Other technologies

Other EOR technologies (SPE International, 2011) that are reported to have emerged according to the Society of Petroleum Engineers are listed below:

- Advanced polymers:
    - New design and manufacture of polymers with a narrow range of molecular weights by PetroChina which can be tailored to an application and is also economical in lower permeability formations;
    - In-depth diversion technology – thermally activated plugging agents; and
    - Foams – currently under laboratory testing.
- Chemical flooding:
    - Advances in surfactants – Surfactants that are thermally stable (e.g. sulphonates) removing temperature restrictions, active at 0.1% concentrations and which are sacrificial agents (e.g. sodium carbonate) that reduce adsorption to very low levels; and
    - Alkaline flooding - alkaline-polymer (AP) and alkaline-surfactant-polymer (ASP) that are lower cost EOR methods.
- Thermal Recovery:
    - Controlled combustion (THAI – Toe to Heel Air Injection) – removes, depth and pressure restrictions of steam and is applicable to light oils;
    - Steam-assisted gravity drainage (SAGD) – Uses horizontal wells to contact formation and reduce well costs and modifies steam drive; and
    - Microbial EOR (Glorienergy, 2015).

A wide range of different chemicals are used, and their environmental hazards/risks vary. There have been efforts to identify more "environmentally friendly" chemicals[26].

Potential benefits and risks

Enhanced recovery is not a new concept but the technologies are constantly being renewed and updated. These kind of operations will all impact upon the environment in the event no proper risk management measures are in place. Environmentally there is potential risk and impact to the air, land, sea and surface runoff pollution. In the past, ER technologies were evaluated to have significant potential for environmental impacts including pollution of land and surface water from spills and leaks of oil, produced water and other chemicals, loss of biota, contamination and deterioration of surface and groundwater, excessive emissions to air from thermal techniques and erosion to land. This means that proper environmental planning (including monitoring, protection measures, and reclamation strategies) must be carried out as part of the planning of the field (Millemann, 1982). More modern techniques and better awareness have since been integrated into any new advances, and several forms of enhanced recovery are considered to be mature. Environmental risks that arise when

[26] http://www.statoil.com/en/TechnologyInnovation/OptimizingReservoirRecovery/RecoveryMethods/WaterAssistedMethodsImprovedOilRecoveryIOR/Pages/ChemicalFlooding.aspx

using ER technologies that are regarded as mature for onshore and offshore conventional wells are discussed in Sections 5.4.12-14 and 6.4.15-17.

The following environmental aspects would benefit from further research for the potential incremental effects on the environment compared against existing technologies and processes:

- Ground water contamination;
- Surface water contamination;
- Biodiversity impacts; and
- Releases to air.

Some example of the impacts to environment, in particular Carbon Capture and Storage (CCS) and subsea compression are discussed below.

CCS technology

Highlighting the EOR technology for CO_2 sequestering, the benefit to the environment is that CO_2 (linked to global climate change) can be captured from the power plant industry or any other heavy industry and used as part of the enhanced oil recovery process. The studied risk of CO2-EOR was that there are potential incremental environmental risks such as: subsea CO_2 leakage, CO_2 impurities, potentially toxic trace elements in produced water, and radioactive scaling. However from experimental findings by the University of Edinburgh (Kit Carruthers) for the Scottish Carbon Capture and Storage, it was concluded that CO_2-EOR, provided it is managed properly, would present "no significant incremental environmental risk" compared with current oil and gas operations (Carruthers, 2014).

Even though the benefit to the environment is that the carbon is captured from the power plants and other similar operations, and stored rather than released into the atmosphere, there are still significant environmental impacts from the CO_2 production itself and the construction of the facilities and related infrastructure to capture and treat the CO_2 (NOAH, 2014).

The lithology on the reservoir top (the caprock) is very important in that it must be impermeable to CO_2, therefore preventing CO_2 migration upwards and eventual reach to the surface. If such an event occurs, resulting from natural migration pathways, such as existing boreholes, recent faults or even outcropping permeable formations, the movement of CO_2 has to find its way up passing through several layers of (probably different) lithology with also different permeability. An eventual leakage from underground is a slow process that may last for decades or even centuries, depending on the diffusion capacity of the CO_2 through the geologic formations above the reservoir layer, until the CO_2 finally reach the surface. The magnitude of an eventual underground leakage may be predicted by the required 3-D dynamic geological model of the reservoir formation and the neighbours' lithologies (Barros et al, 2012).

Subsea compressions (Turbomachines, 2015)

Environmental issues would still need to be assessed properly, with challenges such as the hard environment conditions of the sea and the increased likelihood of corrosion. Some operators are moving towards the use of subsea compressors (e.g. Statoil) but it is not widely implemented at the moment. Some environmental impact and risks would be present and many can be assumed from the subsea pipelines assessment. Risks and impacts include:

- Leakage of production fluids at various connections and rupture in processing equipment;
- Mechanical failure due to corrosion and erosion (Chemical reaction and high-temperature fluids or abrasive materials (e.g. produced sands));

- Absence of detection systems for subsea;
- Chemical release (monoethylene glycol or methanol, chemicals used to remove water, paraffin and other flow-inhibiting hydrocarbon substances in the oil and gas from the entrained water in the flowlines). Large volumes of release would be problematic but small and chronic leakages are considered to have a small impact due to a large dilution effect. Notwithstanding that, chronic leakages can be considered to have a larger impact if such small and chronic leakages are coming from a number of wells condensed within the same area, or in the case of particularly environmentally hazardous and/or persistent substances (if used);
- Habitat disturbance from installation of infrastructure creating long term loss of habitat and smothering of colonies from suspended particular arisen from seabed disturbances; and
- Risk from accidental events resulting in spillages and leakages directly into the seabed.

There may be benefits from ER methods as they extend the lifespan of the oil and gas reservoirs thereby putting off the requirement to drill new wells. However whether ER methods could yield the same quantities commercially depends on the cost effectiveness to deploy commercial quantities of hydrocarbons as compared with the cost to drill and extract hydrocarbons from a new well. Further studies would be required to assess the comparative risks and impact to the environment of all different ER techniques.

3.3.2 Robotics

3.3.2.1 Background

The production of oil and gas from more extreme environmental and geographic conditions has posed a challenge for oil and gas companies in managing human safety and environmental impacts. Robots that are semi-autonomous are being increasingly utilised by the oil and gas industry to help manage these issues, and have the potential to be used more widely in all off-shore and on-shore operations. Semi-autonomous robots are already a form of commonly applied technology in other industry areas such as the automotive sector and space programmes. To this end, the use of robotic systems is now gathering increasing interest for use in the oil and gas industry. For example, in an industry which relies heavily on human ingenuity and hands-on experience, automating repeatable tasks usually carried out by deckhands, roughnecks and pipe-handlers may be one way to help solve the growing problem of reduced numbers of skilled rig workers (Financial Times, 2014).

Other applications may include use in investigating the rig structure and drilling activities at the sea bed, where use of human personnel poses particular risks due to the nature of the tasks and environment presented. In many cases, robots are seen to be useful from a safety point of view, allowing various dangerous operations to be replaced with robots. This has become increasingly possible with more advanced techniques, increased artificial intelligence and sensitivity of the equipment.

A growing number of companies are currently working on different applications that utilise this kind of technology. The ongoing research includes manufacture of intelligent drill bits able to respond instantly to conditions such as extreme temperature or high pressures. Examples include National Oilwell Varco and Schlumbeger (SLB) which developed a drill pipe wired with high-speed data lines to allow the drill bit to feed information to workers at the surface. Apache is writing a software programme that allows the drill bit to think for itself, which then communicates and interfaces with the equipment at the surface controlling speed and direction of the drilling activity. For onshore, breakthroughs are taking place with a rig that is able to move by itself to the desired location without the need to dismantle any structure (Bloomberg, 2012). Further descriptions of selected applications that have environmental focus are discussed in subsequent sections.

3.3.2.2 Application

There are many robotics technologies being used globally and often for offshore applications such as in the fields of maritime security, underwater archaeology and marine biology. Robotic applications are wide ranging and can be applied to many areas of the oil and gas industry. Some of the main areas are summarised below (Chen et al, 2014).

Mobile Platform

Remotely operated underwater Vehicles (ROVs) are widely used in subsea operations to install equipment, perform maintenance and carry out repair tasks. ROVs are connected by a cord cable, with information transmitted from the remote controller to the ROV helping it carry out different tasks. The cable also provides the necessary electrical power. From picking objects, to moving around, ROVs have a number of viable capabilities to assist in offshore oil and gas production.

Teleoperation

Instead of building an offshore surface platform to drill for oil and gas at the seabed (which can be up to 3000 metres below sea level), exploration companies are able to use the 'Seabed Rig system' to drill, using robotics, with only a support vessel at the surface (Chen et al., 2014). The robotic system handles pipe and tools and can be applied to both on pipe-deck and drill-floor on all drilling structures (new builds and retrofit) for both land and offshore installations. It ensures fast and precise work operations between the electric drill floor machines. This decreases the potential for human error, reduces the time required for drilling operations and costs less than conventional drilling platforms to install. Additionally there are other opportunities for robotic systems in seabed operations besides drilling, including automated seabed maintenance and repair systems, automated seabed inspection systems and ROVs. The risk of incidents and accidents cannot be ruled out completely, as where manual manipulation of the robotic equipment is required, there is still the potential for human error which could result in an incident impacting upon the environment.

Automated Equipment

Automated equipment is often preferred by the oil and gas industry for processes that are repeated many times during exploration and production. Seabed drilling systems are an example of such a process. Robotic drilling systems, such as the one developed by Seabed Rig, is considered extremely useful for simplifying the drilling process and ensuring that it is very accurate. Most drilling processes are very labour intensive and require continual human supervision, which could be replaced by robotic systems.

The industry report on 'Global Underwater Robots Market 2015-2019' provides details of growth prospects for further use of robotics in oil and gas over the coming years globally. Atlas Maridan ApS, Bluefin Robotics Corp. and Deep Ocean Engineering Inc. are identified as key influences in the underwater robot market.

3.3.2.3 Case studies

Further specific examples of robotic applications that have emerged are outlined below:

Liquid robotics - Wave Glider (Forbes, 2012)

Wave Glider is a robot that is over 110kg which is powered by wave and solar power and is of a similar size to a surfboard. These are understood to be able to roam the world's oceans autonomously for up to one year. The bots are equipped with cell phone flash storage, a dual-core ARM processor which runs on Linux software, a battery pack, sensor arrays, a GPS unit and wireless and satellite communications systems. The solar panels power the equipment, whereas the undersea fin which taps into the up and down motion of the ocean waves is used for propulsion.

The type of information the wave gilder can collect includes ocean currents, seismic monitoring and detection of seepage from pipelines and oil drilling. Liquid Robotics, who manufacture the wave glider, have deployed over 100 of their robots globally, working in collaboration with climate scientists, the oil industry and the U.S military. The technology is indicated to be cost-effective with low labour requirements and use of boats to acquire the data. This reduction in the need for boats and fuel use associated with marine navigation is sited as being more environmentally conscious than typical maritime surveying methods.

The operational challenges faced by using this kind of equipment include accumulation of sea scum and barnacles which can collect and interfere with the robot functions, locating the robots in open sea for collection (even with GPS installed) and sea slime building on top of the solar panels. The advantage that this type of robot technology can offer includes withstanding severe weather, glassy seas, strong currents and low solar environments; large data storage capacity and operating autonomously for years with no need to re-fuel, emissions or crew (Liquid Robotics, 2015).

BP have stated that the wave glider robotic system was able to achieve (BP, 2013(b)):

- A Wave Glider fleet, which has cumulatively been at sea for 11.5 years and has covered over 100,000 miles;
- A single Wave Glider, launched in December 2008, has been at sea for over 600 days, travelling 15,500 miles. This model called 'Stripes' is still swimming, with minimal maintenance required to date;
- Two Wave Gliders, 'Honu' and 'Kohola', travelled from Kona, Hawaii to San Diego, California – 2,750 miles in 79 days; and
- A Wave Glider, 'Red Flash', travelled from Mexico to Alaska and held station in 21 foot seas and 50 knot winds.

Apart from BP, Conoco Philips and Schlumberger have reported utilisation of this type of technology. Liquid Robotics and Schlumberger in particular have worked in a joint venture to deploy these robots to provide exploration of subsea geology and monitoring services for the offshore oil industry.

Remotely operated Vehicles (ROVs) (ChaiOne, 2014)

Frequently used in offshore deep water systems, ROVs provide better underwater capabilities. The ROV consists of a vehicle, tools and sensors, control/display consoles and electric power distribution.

ROVs are easily deployed and can come in a range of sizes. Manpower is minimal as usually only one person is required as a controller. This technology also allows complicated functions such as picking up objects or manoeuvring. However there are many disadvantages of the use of current ROVs. A particularly troubling issue is in deep sea areas where the cables can become easily tangled because they extend from the vessel to where the ROV is located. Once an ROV is tangled, the cables have to be cut. ROVs are high maintenance and can be affected by sea currents.

Example companies such as Statoil are using ROVs in the oil and gas sector, with vehicles capable of diving to depths ranging from 100 to 2,500 metres in the Barents and Norwegian seas. ROVs are used to visit various rigs in these areas. Another example, Total E&P UK recently used a ROV for a Laggan Drilling Project to explore deep water ecology. Hurricane exploration have used ROVs to investigate the seabed of the site after the hurricane event. The most notable recent example of ROV application is BP, where ROVs were used to attempt to plug the leaking oil well in the Gulf of Mexico (2010).

Further advances in this technology can be shown in the example of the Schilling ROV Explorer which offers an automation system that can notify users through texts and emails when equipment may require maintenance. The product movement from field to the terminal can also be controlled using this mobile-based system. One of the benefits of such a system is that the ROVs can be controlled wirelessly and with a mobile or tablet app. Other applications of this technology include the Underwater Wireless Sensor Network (UWSN) and the Aqubotix-Hydroview underwater vehicle.

Mini-Robot to Enhance Pipeline Inspections

Pacific Gas and Electric Company (Energy global, 2013) (PG&E US and Canada) jointly with NYSEARCH, National Grid, Rochester Gas & Electric, New York State Gas & Electric and Honeybee Inc are all involved with the development of a robotic equipment that enhances the companies' ability to visually inspect natural gas pipelines for signs of corrosion. In 2013, OG&R tested a wireless controlled 20ft long robot which inspects gas transmission pipelines in order to increase their pipeline safety. The robots use a high-definition camera, super-sensitive detectors and a laser probe to inspect pipeline dents, cracks or corrosion without the need to take the line out of service for inspections.

The wireless feature on the Explorer robotic tool allows it to function without being tethered and propelled by natural gas as compared with traditional "smart pigs". The advantages also include navigation through live pipelines that are considered "unpiggable" because of low pressure conditions or other restrictions such as sharp bends and plug valves.

While this specific technology is commercially available, there is no evidence found to indicate its widespread application, although it does present a potential option for further utilisation within oil and gas production lines.

Other technologies

Some other technologies identified (Heping et al., 2014) include:

- Deep Water Pipeline Repair Robotic Systems (e.g. used by Statoil, Chevron);
- SINTEF Topside Robotic System which allows areas of the offshore rig to be unmanned;
- Fraunhofer Inspection Robots that detect and map damage precisely, and can conduct façade cleaning;
- CMU Inspection Robots can be used to conduct simple inspection and monitor hazardous and remote facilities;
- In-pipe inspection robots (IPIRs);
- Tank inspection robots (TIRs); and
- Automated core flooding capability (first system in the world) which transforms the number of enhanced oil recovery (EOR) core flood tests from tens to hundreds a year with the robot working 24/7.

3.3.2.4 Potential benefits and risks

The production of offshore oil and gas presents inherent risks to both the safety of human health for personnel at sea, and the potential environmental impacts from production processes. The safe production of oil and gas offshore requires the use of skilled personnel and careful management of the processes being used. The application of semi-autonomous robotic equipment to carry out repeatable tasks, particularly at sub-sea level, will reduce the risks for human health and safety, as well as reducing the risks for environmental impact. This comes about partly through the reduction of incidents related to human error, but more so because it gives oil and gas operators' greater capacity to inspect and maintain equipment at sea depths which are restricted by the use of conventional equipment. The design and development of these applications is also increasingly making use of energy sources such as solar power which reduce the need for survey options powered by marine fuel oils. Risk and impacts to the environment would still be considered possible due to accidental incidents, robots failing, etc. However to prevent/mitigate these incidents again would need to rely on adequate risk management measures, careful maintenance and frequent inspection and even that could still be prone to human error. The potential environmental aspects of robotics in relation to accidental events (compared to existing technologies and processes) would therefore benefit from further research.

3.3.3 Seismic technologies

3.3.3.1 Background

New advanced seismic imaging technologies are being developed to enhance understanding of reservoir structures, in order to reduce risks and increase accuracy of determining reservoirs with commercial potential. In many instances the advances in technology are driven by the need to provide accurate data of the reservoir to reduce risk and the cost of drilling dry wells. As a result of better imaging data, fewer exploratory wells are required, achieving smaller footprints, better protection of groundwater resources, reduced health and safety risks. In the UK in recent years, these new advances have contributed towards the reasons why, despite a decline in exploration activity and lower number of exploration wells drilled, a higher number have been commercially successful. However there are two challenges the industry face: firstly there are issues overcoming the limitations imposed by seismic bandwidth in conventional acquisition techniques, and secondly, in delivering clearer illustrations of the subsurface to their clients who interpret the seismic data (Oil & Gas UK, 2015(a)).

Traditionally, acquiring high-quality 3D seismic data on land is more expensive than it is at sea due to the amount of infrastructure, time and manpower needed. In the conventional example of a land seismic survey, a line of trucks with vibrating plates would park at regular intervals and send sound waves into the ground one at a time, to ensure that there is no interference between their signals and the sound waves reflecting off the rocks in the earth strata. This is then received and recorded by geophones. The reflected sound waves are analysed to produce a 2D picture of the geological structure, and the likelihood of oil and gas reservoirs (BP, 2015(b)). Recent advances indicate that new seismic technology is able to increase the speed and also quality of seismic data acquisition e.g. wireless sensors, autonomous vehicles, 3D imaging, etc. Further emphasis to push towards more advanced seismic technologies is also influenced by unstable oil prices. The need to optimise recovery in existing fields and develop new fields quickly and with greater commercial viability would mean that seismic technology will increasingly become a tool for production work (SPE International, 2015).

3.3.3.2 Application

New advances for seismic equipment considered include the new broad bandwidth technology. This enables seismic data to be recorded across a much wider spectrum of frequencies, from low frequency waves for deeper penetration of the subsurface to high frequencies generating higher resolution images (Oil & Gas UK, 2015(a)).

BP, Fugro, PGS and Schlumberger are among those reported to be pursuing advanced seismic technologies.

Examples of seismic technologies are detailed below:

IsoMetrix Seismic technology

Schlumberger launched a new towed marine technology, IsoMetrix which records broad band seismic data using a point-receiver multi-sensor streamer. This produces a dense isometric grid of data. The technology has provided extremely detailed images of complex geological structures. Models can then be used to interpret from this high quality seismic data and produce isometric grid dimensions of 6.25m x 6.25m which provide significantly more accurate data. This thereby reduces the overall oil and gas finding and development costs.

The technology combined two type of sensors helping to eliminate interfering ghost reflections, maximising the range of frequencies recorded during seismic survey and increased penetration of the subsurface. These types of data result in a clearer imaging and more accurate analysis of the reservoir, thereby providing better accuracy in identifying viable oil and gas fields as well as understanding existing reservoirs (Oil & Gas UK, 2015(a)).

NETL Advanced seismic technologies

3D seismic imaging which is replacing 2D imaging, maps the extent and thickness of oil and gas reservoirs in three dimensions and for identifying fluid-flow pathways and barriers within a reservoir (NETL, 2015(e)). Specialised tools, including multicomponent seismic data acquisition and processing, seismic attribute analysis, wave equation migration, advanced AVO analysis, borehole seismic imaging, and time-lapse imaging are being adopted in combination with advanced log analysis techniques to delineate oil and gas sweet spots, especially in complex reservoirs. Application of these advanced seismic tools and techniques has led to more effective targeting of wells in complex reservoirs, and also overall improvements in oil and gas recovery in existing fields.

The NETL Oil and Natural Gas Technologies Program has developed successful technologies for detecting fractured areas in tight gas reservoirs, for sub-salt imaging in oil fields, for reservoir characterisation using seismic attenuation and for improving seismic image quality and resolution in structurally complex oil and gas reservoirs. It also currently supports projects to develop Fibre Optic micro-engineered mechanical systems (MEMS) based seismic receivers for borehole applications, projects to improve algorithms for using seismic attributes such as attenuation as a direct indicator of reservoir properties, projects to improve the quality and affordability of borehole imaging, projects to develop 3D and 4D multicomponent seismic acquisition and processing systems and projects to integrate seismic and log data into reservoir characterization and basin analysis.

iDAS technology

iDAS technology produced by Silixa has developed an Intelligent Distributed Acoustic Sensor (iDAS), a seismic-imaging instrument which turns a length of standard optical fibre into a string of precision microphones (Oil & Gas News, 2015). It records the full acoustic signal simultaneously at every 1m up to 40,000 data points and is used to collect uniquely high-resolution seismic data from within oil wells and from carbon capture and storage reservoirs. Silixa's technology has turned the optical fibres, which are used in wells to provide information on pressure and temperature, into an optimum sensor array. This can reportedly be done with no additional cost or complexity to the incumbent systems. The iDAS relies on Rayleigh Scattering and launches pulses of light down the fibre which analyses the small amount of light backscattered to determine the change in fibre strain at every metre down the optic tube.

3.3.3.3 Potential benefits and risks

Environmental impact from conventional seismic surveys are currently not considered to be very high (refer to appendix A and B for onshore and offshore risk matrixes). The importance of seismic surveys in exploration has meant a strongly backed development to advance seismic technology in a fashion so as to reduce time required to conduct a seismic survey, and provide a new generation of highly accurate seismic data with detailed images of complex substructure. This improvement would result in reduced time, cost and manpower required thereby reducing the frequency of vehicle movements and resulting emissions from transport and energy generation equipment.

In addition, with fewer wells being drilled due to higher success rates of finding commercially viable reservoirs and the optimisation of the recovery of existing wells, the environmental impact of oil and gas operations generally on the environment should be lower.

3.3.4 Floating LNG

3.3.4.1 Background

Offshore gas fields are a key component of the oil and gas industry and make up much of the global production of natural gas. The continued growth of natural gas production from offshore fields requires the identification of new reserves which can be developed to produce flows. However in many cases those fields identified are beyond the scope of conventional technology because they are either too remote, found within deep waters, or excessively expensive to tap due to a combination of both geology and geography. The steady production of gas from offshore fields requires the laying down of pipelines to feed gas produced back to shore. This is particularly problematic in deep waters where submarine pipelines are particularly challenging and not economical, particularly if the producing well is small (Chiyoda, 2015). Also, the laying of subsea pipelines can have a significant impact on the environment. Arctic environments are a further challenge due to the ice and more extreme weather conditions.

Floating LNG installations (Figure 3.2), which could capture and store the produced gas for return to shore represents a significant advancement in offshore gas technology and removes the requirements for pipelines. This kind of development is now being explored as the next advancement within this field of industry.

Figure 3.2: Example of FLNG vessel

Applications

Chilling natural gas to -162°C (-260°F) creates a liquid with 600 times less volume. This can be contained and then shipped to customers around the world. Traditionally, liquefied natural gas (LNG) was produced in plants built on land. However there have been advances made that will allow the processing (liquefaction) of the gas to be conducted at sea, next to the producing well. The gas can then be contained and then transferred for shipment. An example of this type of application is the floating LNG used by Shell for the Prelude gas field 200 kilometres off the Australian north-west coast (Shell, 2015).

The potential to unlock smaller oil and gas fields economically has recently extended to Petronas' 1.5 Mtpa FLNG-1 for the Kanowit field in Sarawak, Malaysia, and Pacific Rubiales' 0.5 Mtpa plant for La Creciente in Colombia which would not be economical if developed through conventional infrastructures and facilities. Large oil and gas fields can also benefit from the floating LNG technology.

Another challenge for large gas fields in the Eastern Mediterranean is the heavily built-up coastlines with tourism and real estate. Having to locate an onshore plant to process the oil and gas returned to shore by pipeline may require lengthy legal and permitting delays and community objections.

As long seabed pipelines, dredging for jetties or onshore roads and construction are not required, the use of LNG platforms reduces the environmental footprint. Fuel gas is saved from the need to transport the compressed gas to shore. For decommissioning activities, the marine vessel has the potential to be easily removed and re-deployed in other areas (KMPG, 2014).

3.3.4.2 Case study - Browse FLNG Development (Woodside, 2014)

The Browse FLNG Development was been granted Commonwealth environmental approval under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) on 17 August 2015 from the Australian Department of Environment. This is the fifth project utilising the FLNG technology under the EPBC Act. The Browse FLNG will combine the functions of an offshore gas receiving facility, with a gas treatment and liquefaction plant, including the storage and offloading facilities. As a result, it is claimed that this produces a significantly smaller environmental footprint as compared with traditional onshore developments. The subsea layout and the development infrastructure have been designed and located to avoid sensitive habitats (Woodside, 2014).

3.3.4.3 Potential benefits and risks

Floating LNG installations considered to have a smaller environmental footprint compared with an onshore facility due to the combination of traditional offshore and onshore facilities into a single FLNG facility. The avoided environmental impacts include:

- Avoided requirement for pipeline installation to shore;
- No seabed dredging and clearing required which would have resulted in land and seabed disturbances;
- Minimised construction and operation risk in sensitive coastal and marine environments;
- Minimises the amount of construction material needed to construct the facility; and
- The FLNG installation itself can be considered more environmentally sustainable as it can offer the possibility to be refurbished and re-used during the decommissioning stage.

In the example of the Browse FLNG, an environmental impact assessment was conducted as part of the Environmental Impact Statement exercise. The majority of impacts were assessed to be low risk for planned development activities. For unplanned events, the accidental release of hydrocarbon into the environment was shown to be of most concern. Main risk management measures outlined included (Woodside, 2014):

- Routine discharges and emissions minimised at source using best available technologies and disposal methods;
- Installing appropriate engineering features to reduce the risk of spills;
- Avoid interactions with sensitive receptors such as sensitive habitats; and
- Monitoring discharges and emissions to ensure compliance.

The following environmental aspects would benefit from further research for the potential incremental effects on the environment compared against existing technologies and processes:

- Accidental events.

3.3.5 Drilling technologies – coiled tubing

3.3.5.1 Background (Boumali, 2006)

Coiled tubing (CT) refers to a continuous length of small-diameter steel pipe and related surface equipment as well as the associated drilling, completion and workover, or remediation techniques (Varhaug, 2014). CT can reportedly replace other drill pipes with long and flexible pipe and as a result reduces the cost of drilling, through faster rig set up, the need for less drilling mud and reduction in time needed to make drill connections. Coiled tubing is reportedly advantageous over conventional tubing as these required the tubes to be screwed together. The coiled tubing also does not require a workover rig since the tubing is inserted into the well during production operation. This would be cost-effective and also can be used on high-pressure wells (Rigzone, 2015). A further benefit identified by the Natural Gas Supply Association is reduced impact on the environment (smaller footprint) when coiled tubing is combined with "slimhole" drilling (drilling a slimmer hole) (Naturalgas.org, 2013).

3.3.5.2 Application

Coiled tubing drilling is understood to be becoming a preferred method for underbalanced horizontal re-entry drilling in wells with fragile formations. The faster rig set-up and shorter trip times mean that it is more cost effective and results in higher production rates than conventional overbalanced drilling techniques. Coiled tubing drilling is understood to be particularly cost effective for the mobilisation of a drilling rig situated in remote areas (NOV, 2015).

Coiled tubing oilfield technology was initially developed for the operation of live and producing wells. This technology has multiple applications within drilling operations, including workovers. The cost effectiveness of this technology has also helped this become widely accepted. The trend toward extended-reach wells favours CT for its capability to drill or to convey tools and equipment in high angle wellbores (Varhaug, 2014).

Additionally, some advances in coiled tubing allow for real-time downhole measurements that can be used in logging operations and wellbore treatments. Well stimulation processes, such as low volume hydraulic and acid fracturing, can also be performed using coiled tubing. In addition, sand control and cementing operations were indicated to be able to be performed via coiled tubing (Rigzone, 2015).

3.3.5.3 Potential benefits and risks (Varhaug, 2014)

The risks of drilling for an oil and gas field can depend on whether appropriate risk management measures are put in place and if the drilling technique adopted is appropriate. Compared to conventional drilling and workover operations, the advantages of coiled tubing include rapid mobilisation and rig-up, fewer personnel, smaller environmental footprint by minimising impact to a smaller area and reductions in time associated with pipe handling while running in and out of the hole. Coiled tubing can help the operator avoid the risk of formation damage in a well by allowing continuous circulation during well intervention operations. These advantages may yield significant cost savings over conventional drilling or workover techniques.

3.3.6 Emissions reduction technologies – Dry Low Emissions (D.L.E.)

3.3.6.1 Background

In upstream oil and gas operations where facilities are often located in remote onshore locations or offshore, access to a power grid may be limited or unavailable. Security of power supply is critical to upstream operations. Therefore onsite generation is often employed. On-site turbines can be fitted with DLE systems in order to reduce emissions of nitrogen oxides (NOx) from the combustion process. Modern turbines can be fuelled by either gas or liquid fuels. These units are therefore run on associated gas produced directly from the field or imported liquid fuels. However, the LCP BREF (2006) states that DLE systems which are active during liquid fuel operation are not always available from manufacturers. In heavy oilfields where there is an insufficient amount of associated gas to fuel the power plant, crude oil can be used as the main fuel for power generation, provided that the generation unit is designed to process it (Siemens, 2012). It is unclear whether DLE technologies would function in these circumstances.

The evolution of international legislation around air quality and development of emission limit values for combustion technologies means that onsite power generation from fossil fuel driven technologies requires environmental permits. Additionally many oil and gas companies will have also adopted environmental policies covering the issues around mobile power generation and air quality emissions (Siemens, undated). As new standards for emissions compliance are constantly being addressed and with evolving good environmental policies being made by oil and gas companies, incremental improvements for power plants is driving the necessity to curb emissions.

3.3.6.2 Application

Dry Low Emissions (DLE) reduces the temperature of a combustion chamber with the mixing of the fuel and air before ignition compared with conventional methods of allowing the fuel and air to mix at the point of combustion. DLE results in a lower maximum flame temperature but with the same heat output (Science & technology, 2013). The control in the combustion chamber leads to a reduction in NOx emissions.

DLE was developed as a method of NOx control in gas turbines by several manufacturers in order to achieve low emissions without requiring water or steam injection. A DLE combustor utilises the principle of lean premixed combustion, and is similar to the Single Annular Combustor (SAC) but with the following difference. Instead of one single concentric ring, there are two or three rings with premixers depending on gas turbine type. This layout allows for "staging" as power demand changes, and low emissions can be obtained over the whole range.

To achieve low carbon monoxide (CO) and volatile organic compounds (VOC) emissions, the combustor must provide an adequate residence time. The bulk flame temperature would need to be maintained within a specified limit for NOx and CO concentrations. To fulfil these requirements, the premixing system is arranged into concentric rings in the combustor dome (Sundsbø Alne, 2007).

3.3.6.3 Potential benefits and risks

Emissions to air may be considered to be of lower risk compared with conventional single annular combustion (SAC) combustors. NOx and CO emission guarantees of 25 ppm are usually given when fuel load is above 50 or 75 % for DLE plants (Sundsbø Alne, 2007). However, the emissions tend to stay relatively low across the entire load range. Compared to a SAC plant, NOx production has an increased rate as a bigger load is required due to a higher combustion temperature.

However DLE plants have a higher sensitivity to heating value and fuel quality, while a conventional combustor may not have this issue. The DLE technology would also find that switching between gaseous and liquid fuel challenging. While there are now risk management measures and solutions to the challenges faced by DLE technology, the environmental impacts and risks associated with a conventional power plant would also apply here.

The following environmental aspects would benefit from further research for the potential incremental effects on the environment compared against existing technologies and processes:

- Releases to air.

3.3.7 Nanotechnologies

3.3.7.1 Background

The advancement of nanotechnology has been emerging in many industries in the past decade including the oil and gas sector. Nanotechnology itself is the use of micro-engineered materials with dimensions less than 100 nanometers. The micro-engineering of the surface of nanotechnology can alter the physical properties of a given substance for specific applications. Nanotechnology can be used to alter the properties of materials to produce effects such as magnetism, and allowing materials to become up to 20 times stronger than the strongest modern carbon fibres (Johnson, 2010). The possible properties of nanotechnologies for application within oil and gas include:

- Improved success of exploration by improving data gathering, recognizing shallow hazards, and avoiding dry holes;
- Nanotechnology-enhanced materials that provide strength and endurance to increase performance and reliability in drilling, tubular goods, and rotating parts;
- Improved elastomers, critical to deep drilling and drilling in high-temperature/high-pressure environments;
- Production assurance in diagnostics, monitoring surveillance, and management strategies;
- Corrosion management for surface, subsurface, and facilities applications;
- Lightweight, rugged materials that reduce weight requirements on offshore platforms, and more reliable and more energy efficient transportation vessels;
- Selective filtration and waste management for water and carbon nanotube applications;
- Enhanced oil and gas recovery through reservoir property modification, facility retrofitting, gas property modification, and water injection; and
- Refining and petrochemicals technologies.

Current applications have seen this type of technology push through into exploration, drilling, completion, production and processing and refining. An example of this is the enhancing of the resolution of subsurface imaging for advanced field characterisation techniques. It can enhance oil recovery via molecular modification, manipulate the interfacial characteristics and allow monitoring of deep wells and hostile environments during exploration phase (Ibrahim El-Diasty, 2013).

3.3.7.2 Application

Global applications and research (Ibrahim El-Diasty, 2013)

The applications of nanotechnology are numerous. As demonstrated below, a large range of uses can be developed with this technology for upstream oil and gas processes alone.

Exploration

- Development of sensors and the formation of imaging contrast agents;
- Hyperpolarised silicon nanoparticles for measuring and imaging for oil exploration;
- Nanosensors compatible with temperature and pressure rating of deep wells and hostile environments to provide data on reservoir characterisation, fluid-flow monitoring and fluid-type recognition; and
- Nano-computerised tomography (CT) imaging for tight gas sands, tight shales and tight carbonates.

Drilling and Completion:

- Fluid Loss Control and Wellbore stability: Nanoparticles as drilling fluid additives to reduce the fluid loss and enhance wellbore stability;
- Bit Balling: nano-based fluid for drilling in shale;
- Torque and Drag: nano-based fluid to reduce frictional resistance between pipe an borehole wall;
- Removal of toxic gases: removal of hydrogen sulphide from mud to reduce environmental pollution, health of drilling workers and prevent corrosion of pipelines and equipment;
- High Temperature and High Pressure (HTHP) Challenges: nano technology that addresses the poor heat transfer coefficient of usual drilling fluid systems. The extremely high surface area to volume ratio of nanoparticles enhances the thermal conductivity of nano-based drilling fluids which provides efficient cooling of drill bits, leading to a significant increase in operating life cycle of a drill bit; and
- Increase down-hole tools' lifespan: The nanoparticles have very little abrasive forces and less kinetic energy impact. The nanoparticle can be added in small concentrations of about 1% to the mud which is reported in a conference paper (Amanullah, 2011) to be beneficial to the environment due to the relatively low concentration of nanoparticles required.

Other listed examples of nano technologies include:

- Nanodiamond PDC technology;
- High Strength Nanostructured Materials;
- Enhanced Cement Properties and Cement Spacers;
- Logging-while-drilling (LWD);
- Recovery of hydrates;
- Viscoelastic Surfactant (VES) Stimulation Fluid;
- Scale inhibition;
- Nanosensors for Hydrocarbon detection in Oil-Field Rocks; and
- Oil-Microbe detection tool using nano optical fibres.

Current Oil and gas companies' application of nanotechnology (Bhardwaj, 2014).

Nanotechnology is increasingly becoming an important technology for many oil and gas companies and there is significant investment into this area as it provides advancement and major development for the industry. The list below provides a summarised picture of what new applications current oil and gas companies have used nanotechnology in.

- Shell employs nanotechnology to catalyse chemical reactions for hydrotreating, hydrocracking, hydrogenation and isomerisation (Arabian Oil&Gas, 2015) and also to prevent corrosion of pipes. Research is also being conducted by the multinational oil industry to use the technology in extracting more oil and gas from reservoirs. Extracting oil efficiently from the earth involves using water to force it out from microscopic rock pores. BP currently uses micro and nanofluids on extremely large scale basis for the operation;
- Beijing Woven Energy Technologies is studying the sustainability of Nansulate® High Heat on offshore drilling platforms for insulation and corrosion control. Current reviews of the material have noted the strong performance in harsh offshore environment, preventing offshore oil storage tanks from corrosion and providing thermal insulation;
- ConocoPhilips and the University of Kansas have teamed up jointly to research the development and testing nanotechnology for oilfield stimulation to improve recovery and meet the increasing demands for production;
- Eni has focused on nanotechnology for the evolution of crude oil and gas quality to make it possible to evaluate about 99% of world production of crude on the basis of density (API level) and sulphur content; and
- The Center for Physics at the Venezuelan institute of Scientific Research (IVIC) are seeking to use nanoparticles of metallic salts like iron, nickel and cobalt nitrates as catalysts in processes involved in the oil industries which produces greenhouse emissions. Their aim is to develop catalysts which will fit into the Venezuelan industry and help in reducing greenhouse gas emissions by up to 50% from activities like oil refining and fuel consumption by motor vehicles.

3.3.7.3 Nanotechnology case studies

Nanomaterial Membranes (Johnson, 2010)

Nanomaterials can be used for their potential to improve production and recovery processes during the oil and gas lifecycle. One research project was focused on this idea to produce new types of membranes using nanotechnology. This was conducted at the University of Wyoming.

Gas absorption in conventional methods relies on the differences in chemical or physical interactions where one side of the membrane selectively removes certain components from the gas stream as it passes through to the other side of the membrane. Nanomaterial membranes can be engineered to make it more selective towards a specific gas. The stronger, less brittle and more temperature resistant properties allows the material to remove particles selectively. This also provides the potential for reducing CO_2 emissions in terms of its adsorbent properties.

The adsorbents can also be used to adsorb impurities in oil and gas flows. This technique can also be applied in remediation projects to clean contaminated sites. The adsorbents can capture impurities and release them from the nanomaterial in a controlled environment. Current interest of this technology is for the sequestration of CO_2.

Steel Nanomaterials (Industrial Nanotech, 2015)

Enhancing properties of nanotechnology has led to the development of nanostructured steel surfaces which have improved the physical properties of oil field tubulars, piping and other equipment. Nanostructured alloys for thermal spray coating and weld overlay for hard facing and wear plate applications combine high hardness and toughness properties. This provides high resistance to corrosion, erosion, impact and wear. Nanostructured steel alloys provide a new class of steel, with hardness fracture toughness exceeding conventional alloys. NOV Grant Prideco's Platinum® HB partnered with The NanoSteel Co. for the Super Hard Steel® technology. The engineered material is used in drill string hard banding applications to provide high strength for minimum casing wear performance and tool joint protection as well as high toughness to resist cracking and spalling in severe downhole applications.

Nanotechnology in Proppants

Effective proppants using nanotechnology is another emerging method for hydraulic fracturing. The proppants pumped into the tight rock formation create pathways for oil and gas to flow into the well bore. Due to the steep decline curve on most shale and tight sand wells, lighter-weight and stronger proppant is required in order to reach deeper into the formation without being crushed or settling out. The nanotechnology used in the proppants was able to achieve initial production by up to 50% as well as also slowing the steep production declines. This initiative is being carried out at Rice University which led to the commercialization of OxFrac™ and OxBall™ as well as a new company, Oxane Materials from this research. Going further with this study, the next step is reportedly to apply tracking abilities to precisely locate where the proppants go. To apply this, adding magnetic sensing properties to the nanoparticles is currently being researched. This can lead to the ability to assess the effectiveness of a treatment, or possibly during production or waterflooding operations to determine proppant flow back.

3.3.7.4 Potential benefits and risks

The environmental impacts of nanotechnology itself is currently unknown. Very little is known about what happens to synthetic nanomaterials in the environment and the likely impacts such as ecotoxity. Suitable method to detect nanomaterials is still being sought (Nanowerk, 2012) therefore potential risks from pumping nanomaterials down active wells is not known. Further studies on the short-term and long-term impact will need to be carried out. However its application over the whole range of oil and gas processes has the potential to create beneficial impacts such as in particular risk management aspects of environmental impacts. Such examples include monitoring of drilling wells and pipelines for leakages and cracks, preventing the need to deplete valuable resources such as water, etc. Nanotechnology also allows effective treatment of impurities and emissions in a more controlled environment, and is an effective aid in CO_2 sequestration.

The following environmental aspects would benefit from further research for the potential incremental effects on the environment compared against existing technologies and processes:

- Ground water contamination;
- Releases to air;
- Discharges to sea; and
- Accidental events.

3.4 Summary and conclusions

The development of new technologies is a key component to the innovation of continued oil and gas production across the globe. This is particularly important where oil and gas reserves continue to fall and the identification of new oil and gas fields can sometimes be found within geologies or geographies that are hard to access.

Where new technologies are originally developed to manage issues with particular problems, such as the use of ROVs within deep waters, we are beginning to see that future technologies are now influenced by the need to maximise oil and gas production, cost effective ways of drilling and producing and to a lesser extent, reacting to changes in environmental regulation and climate change legislation. The development and commercialisation of such technologies can prove to have additional widespread application in all operations and bring benefit to the entire industry. The technologies covered within this note are all proven emerging technologies which have the capacity to be used broadly across the whole oil and gas industry.

Figure 2.24 provides an overview of each technology area including whether it relates to offshore operations, onshore operations or both; brief details of what the technology offers; and some general comments about the potential benefits and impacts. However where these are emerging technologies it is not possible to fully assess all risks and benefits presented by each technology area and the commentary provided within this note is intended to be for illustration only. For example the nano-technologies area is one that is particularly diverse and has wide implications for the strength and cost of construction materials, but also in the materials used to help facilitate flow of oil and gas such as proppants. However where nanomaterials are such a diverse set of substances the full risks and impacts are still unknown. In addition, areas for further research on environmental impacts and risks were identified for enhanced recovery, robotics, FLNG, DLE and nanotechnologies.

Potential uptake rates for emerging technologies over the next 5 years have been estimated as either 'highly likely or 'less likely' using expert judgement. It has not been possible to give a quantitative indication of future uptake rates for these technologies at the time of writing, due to a lack of available information.

The technologies provided are intended to provide an overview of the key areas in which the oil and gas industry are currently pursuing innovation in order to maintain the development and production of oil and gas. Additional unproven emerging technologies not covered here would extend beyond the scope of this review and would include prototypes which are novel and yet to reach full commercialisation.

Table 3.1: Overview of the emerging technologies discussed

Technology Area	Onshore/ Offshore	Stage of life-cycle where technology is Applied	General description of the technology	Potential benefits/impacts	Potential uptake of technology
Enhanced recovery and well stimulation	Both Offshore and Onshore conventional	3) Production	Use of mixed gases and fluids, new technologies (e.g. nanotechnology), new techniques to enhance recovery.	Improved production from existing oil and gas fields, reduces the need for new fields in the short to medium term. Potential risks from increased produced water volumes, increased risks of chemical spills and increased releases to air from power generation.	Highly likely
Robotics	Offshore conventional and unconventional	3) Production, also potential application during 2) well design and construction and 4) cessation and well closure	Use of semi-autonomous robots to carry-out repeatable tasks, particularly with environments which pose high risk to human health.	Reduced accidental events from human error. Improved capacity for monitoring reducing the impact of leaking hydrocarbon events.	Highly likely
Seismic technologies	Offshore/Onshore conventional and unconventional	1) Exploration	Use of advanced techniques to provide higher quality seismic data of sub-terrain geology.	Improved seismic data reduces need for more exploratory wells. Reduced environmental footprint for exploration and improved characterisation of underground risks.	Highly likely
Floating LNG	Offshore conventional and unconventional	3) Production	Use of production facilities to collect and store gas at sea negating the need for pipelines and onshore processing facilities.	Reduced need for pipelines and related issues reduces impact on seabed. Reduced impact on shoreline from onshore processing facilities. Increased risk of releases from platform / accidental events of the platform	Less likely
Drilling technologies – Coiled tubing	Offshore/Onshore conventional and unconventional	2) Well design and construction and 3) production during work overs	Use of flexible drilling technologies to improve drilling and reduce set-up needs speeding the process.	Reduced drilling times during exploration and well construction mean smaller environmental footprint of drilling as less equipment and transport needs.	Highly likely

Technology Area	Onshore/ Offshore	Stage of life-cycle where technology is Applied	General description of the technology	Potential benefits/impacts	Potential uptake of technology
Emissions reduction – DLE	Offshore/Onshore conventional and unconventional	2) Well design and construction and 3) Production	Use of pre-mixing facilities to improve combustion efficiency and reduce air quality emissions.	Reduced air quality pollutant emissions from more efficient combustion of fuel. Possible loss of flexibility in fuel use as DLE combustion is linked to specific fuel types	Less likely
Nano-technologies	Offshore/Onshore conventional and unconventional	Potentially all life-cycle stages	Micro-engineering of surface properties for nano-particles (<100nm diameter) to produce specific physical qualities. Multiple applications including development of high tensile strength light weight structures.	Numerous potential benefits across all life-cycle stages. Risks of using nano-materials are unknown.	Less likely

4. Approach to risks and impacts

4.1 Introduction

This section presents an assessment of the identified risks and impacts of the processes and technologies used in the exploration and production of CFF onshore and offshore. The risk characterisation approach used is consistent with that used in the Amec Foster Wheeler (2015a) study 'Technical Support for the Risk Management of Unconventional Hydrocarbon Extraction'.

4.2 Approach

4.2.1 Overview

The risk characterisation approach involved the use of a risk matrix by which to qualitatively rank the risks identified. A qualitative approach was used due to the lack of quantitative data available across the range of stages and activities.

A risk matrix based on King (2012), was developed and agreed as part of the study 'Technical Support for the Risk Management of Unconventional Hydrocarbon Extraction'[27]. The matrix is similar to that set out in AEA (2012). The matrix is not identical to that used in AEA (2012) as it incorporates subsequent developments. The matrix in Figure 4.1 has been adapted to retain the salient elements of the table presented by King and AEA but with further tailoring of the descriptions to help retain continuity with the Amec Foster Wheeler (2015a) study. The matrix provides a systematic approach to characterise risk based on the likelihood that an incident will occur and the potential consequence of that incident. The matrix scores risk as the product of likelihood and consequence. The highest scores are awarded to combinations of high likelihood and catastrophic consequence (and vice versa). The risk score permits risks and impacts to be compared.

The risk rankings for each aspect in the report were assessed using expert judgement and relevant literature. They were also reviewed against previous reports for the Commission (e.g. AEA (2012)) for coherence. It is recognised that in reality risk varies based on many site-specific factors. Therefore, the rankings have been provided for illustrative purposes only, and should not be considered as universally applicable to all hydrocarbon exploration and extraction activities.

For instance, it is recognised that the likelihood of accidental events may increase when oil and gas activities are located in deeper and rougher waters.

In the case of extended lifetime of wells, risks in general are likely to be increased, given the increased duration of operation, and the increased potential for failure with older assets.

The following approach was used to characterise the identified risks relating to the processes and technologies identified in Task 1:

Step 1: Identify the environmental aspects that are relevant to the processes and technologies;

Step 2: Consider the risk management measures assumed to be in place that relate to the environmental aspect and risk. This drew on the AMEC (2014) work on shale

[27] http://ec.europa.eu/environment/integration/energy/uff_studies_en.htm

gas as relevant and also any further identified mitigation where risk management measures were likely to be applied as part of normal practices[28]; and

Step 3: Characterisation of the risk using the risk matrix.

The consequences of the risk were assumed to have direct impact on the environment only. The evaluation did not directly assess workers' health and safety as this was specifically excluded from the study terms of reference. The definitions derived for consequences and risks are based on the nomenclature of King (2012) and AEA (2012).

For each of the stages a range of environmental aspects were examined. For onshore activities the following were examined:

- Groundwater contamination and other risks;
- Surface water contamination;
- Water resource depletion;
- Releases to air;
- Land take;
- Biodiversity impacts;
- Noise;
- Visual Impact;
- Seismicity; and
- Traffic.

For offshore activities, the following environmental aspects were examined:

- Seabed disturbance;
- Discharges to sea;
- Physical presence;
- Releases to air;
- Marine biodiversity impacts;
- Accidental events;
- Visual impact (for near shore operations); and
- Underwater noise.

[28] Measures that mitigate environmental risk are already adopted by operators (e.g. due to standard industry practice, or to minimise financial risk of investments). It was assumed therefore, that measures that are likely to be applied by operators are in place to mitigate risk when using the matrix to assess the degree of risk.

Figure 4.1: Risk Matrix

			Consequence of Incident					
			1	2	3	4	5	
			Slight	Minor	Moderate	Major	Catastrophic	No data
Likelihood of Incident	1	Extremely Rare	1	2	3	4	5	Not classifiable
	2	Rare	2	4	6	8	10	
	3	Occasional	3	6	9	12	15	
	4	Likely	4	8	12	16	20	
	5	Highly Likely	5	10	15	20	25	
		No data	Not classifiable					

Key

Colour	**Level of Risk**	**Score**
Green	Low	1 – 4
Yellow	Moderate	5 – 8
Orange	High	9 – 12
Red	Very High	15 – 25

4.2.2 Consequence

Consequence was assigned as follows:

- **Slight.** These are incidents which will have immediate but short term impact on the environment which naturally remediate after a few days/weeks. Where the severity is 'low', it would have direct impact on environment with noticeable effects, but these would be limited, i.e., not causing death of flora and fauna. An example of a short term, low severity incident within the 'slight' category is drilling equipment running with poor efficiency causing a short term spike in the concentration of air pollutants (such as oxides of nitrogen and oxides of sulphur) which would affect people and the environment. Once the issue was rectified effect on people and environment would return to pre-incident conditions within a few hours/days;
- **Minor.** These are incidents which will have both an immediate and longer term effect (e.g. weeks/months) and take a number of months for the environment to naturally remediate, or require physical intervention to remediate the effects. The level of severity is again 'low', i.e. they will have a noticeable effect on environment without causing widespread death of flora and fauna. An example of an intermediate term, low severity event is a minor leak from the well head which causes land contamination by produced fluid;
- **Moderate.** These are incidents which will have an immediate and long term (e.g. years) effect on the environment. Severity will be 'low', including chronic but not fatal effects on the environment. An example of a long term, low severity incident might be a loss of produced water at surface level (containing remaining fracturing fluids and other contaminants) into waterways causing an increase in concentrations of NORM and metals in river sediments. Effects will be likely to last

for several years without direct intervention but dilution rates will limit the effects of the raised levels;

- **Major.** These are incidents which will have an immediate effect both on a short term basis (hours/days) and also longer term (weeks/months/years). However these events can be remediated with direct intervention within a number of weeks of the incident. The level of severity in these incidents will be high causing widespread death to flora and fauna with significant impact on ecosystems and local populations, but with managed response the effects should be short term. An example of a short term high severity incident classed as 'Major' may be a spillage of large volumes of undiluted chemicals into a waterway causing severe effects on aquatic health; and
- **Catastrophic.** These are incidents which will have an immediate and prolonged effect on the environment lasting several years. The effects of the incident will be severe and widespread causing death to flora and/or fauna or irreversible damage to the environment for several years. The incident is also potentially likely to damage natural resources in a near-irreversible fashion, requiring several years for the environment to return to pre-incident conditions. An example of a long term, high severity incident might be extensive contamination of a groundwater aquifer with hazardous and non-degradable fracturing chemicals.

4.2.3 Likelihood

The following likelihood categories have been used. The assessment assumes that risk management measures likely to be applied by industry (BAU measures) are in place[29]. Cases where such measures are not in place would have a higher likelihood.

- **Extremely rare.** No known events of the risk under review have taken place within the industry within Europe or elsewhere;
- **Rare.** Incidents may have occurred within the industry (Europe or elsewhere) previously but at a very low frequency;
- **Occasional.** These are incidents that should not occur under standard practices. These incidents will however be more common place, for example those that are known to have happened historically at several companies during operations in Europe or elsewhere;
- **Likely.** These are incidents which are likely to occur. The frequency of events is more difficult to predict, but should be assumed to have happened several times per year at different operating companies; and
- **Highly likely.** These are incidents which are highly likely to occur. The frequency of events is more difficult to predict, but should be assumed to occur several times per year (or all the time) in each well location. Incidence of the issue is well documented within the industry with good practice guidelines warning of its potential.

4.2.4 Approach to accidental events

As part of the review of environmental aspects consideration has also been given for accidental events that can occur onshore and offshore. This makes use of a three tiered level of escalation/magnitude defined by the oil and gas industry association IPIECA and detailed more fully in section 6.1.5.

Further detail of the offshore accidental events is given during the risk/impact assessment in section 6.

Where the impacts of offshore accidental events have been categorised using the IPIECA tiered approach, efforts have been made to substantiate the assignments of

[29] See section 3 of AMEC Foster Wheeler (2015a) for a full description of the approach.

'likelihood' made using expert judgement with statistical data. The majority of this statistical data is derived from industry risk assessments or guidance for risk assessments. It should be noted that the data is based on the failure rates of equipment for risk assessments and therefore does not include human factors. Likewise, historical failure rate data are not necessarily representative of current assets. For this reason the probability of some incidents may be underestimated and the results should therefore be treated as indicative only.

For Onshore activities a similar review was carried out but found less readily available data to provide examples in Europe. However the research has indicated that a number of incidents for extremely high levels of widespread damage were from exploding pipelines. As these occurrences are further downstream of our indicated onshore processes, these are therefore considered to be out of scope for the study. The remaining risks for onshore accidental impacts include minor risks such as loss of containment in storage/well head. These impacts are considered to have been addressed within the general risk assessment conducted in this study and therefore have not been detailed further within the results of the study. As offshore activities inherently have a more challenging and harsh environment to work in, the number of incidents would be greater in comparison to onshore activities. Therefore a greater consideration is provided for accidental events for offshore activities and is reflected in the matrix table (see Appendix B).

4.2.5 Approach to cumulative impacts

The risk is assessed on the life cycle of individual oil and gas project sites. Compared to unconventional oil and gas operations, conventional operations are expected to have fewer wells operating within the same area. Therefore with the wells being less densely packed, the cumulative impacts over more than one well in the same area is not expected to be as significant as unconventional oil and gas (all other things being equal). Cumulative impacts from operations of several oil and gas project sites were not assessed specifically in this review.

5. Risk and impacts of onshore activities

5.1 Overview

The following sections outline the identified risks for onshore activities. The identified risks both with and without expected mitigation measures are presented. Further details are provided in Appendix A.

Note that the summary tables below include both mitigated and unmitigated risks. The other tables refer only to the risk characterisation with expected management measures in place.

5.2 Stage 1 Site identification and preparation

5.2.1 Summary of environmental risks

The identification of suitable sites for well placement, preparation of ground and movement of materials using heavy equipment are activities considered for Stage 1 site identification and preparation, for conventional production of oil and gas. The processes for stage 1 that are assessed are as follows:

Sub-stage 1 Identification of resource

a. Desktop studies
b. Licensing

Sub-stage 2 Surveys and conceptual model

a. Aerial surveys
b. Geophysical investigation – seismic surveys
c. Development of conceptual model

Sub-stage 3 Site Preparation

a. Baseline surveys
b. Mobilisation of drilling rig and equipment
c. Site preparation

A summary of risk characteristics for stage 1 site identification and preparation are outlined in Table 5.1. Further details of the risk assessment can be found in appendix A.

Table 5.1: Summary environmental hazards and risk level for stage 1 site identification and preparation

Processes/ technologies	**Environmental Aspects**	**Risk Characterisation** (**with** expected management measures in place)			**Risk Characterisation** (**without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
1. Identification of resource (desktop study)							
1.1 Identifying target area for favourable geological conditions and Licensing	Desk based task - no specific risks identified so not considered further.						
2. Surveying							
2.1 General investigation: - Aerial survey of land features e.g. satellite imagery, aircrafts, etc.	• Releases to air (local air quality)	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
2.2 Geophysical testing/investigations: - Seismic surveys	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	5 moderate
	• Releases to air (local air quality)	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Land take	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low
	• Biodiversity impacts	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Seismic	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Traffic	Likely	Slight (short term	4 low	Highly likely	Slight (short term	5 moderate

			definite)			definite)	
2.3 Development of conceptual model	Desk based task - no specific risk identified so not considered further.						
3. Site preparation							
3.1 Baseline surveys (ecology, hydrology, groundwater, community impact, etc.)	Investigative task – no specific risk identified so not considered further						
3.2 Mobilisation of drilling rig and equipment and people to the drill location	• Surface water	Rare	Slight	2 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
3.3 Site preparation (e.g. site clearing, accessibility, infrastructure, etc.)	• Surface water	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Likely	Slight	4 low	Highly likely	Slight	5 moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Land take	Likely (short term definite)	Minor	8 moderate	Highly likely	Minor	10 high
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Biodiversity impacts	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Noise	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Traffic	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low

The list of processes and technologies assessed to have possible impact in stage 1 include:

- General investigation - Aerial surveys;
- Geophysical testing/investigations – land based seismic surveys;
- Mobilisation of drilling rig and equipment and people to drill location; and
- Site preparation (e.g. site clearing, accessibility, infrastructure, etc.).

The following sections outline environmental risks for the identified list of processes and technologies in further detail.

5.2.2 General investigation – aerial Surveys

5.2.2.1 Overview

The main environmental aspects during the initial general preliminary investigative work for oil and gas exploration are largely attributed to aerial surveys. Aerial surveys conducted by low flying aircrafts will result in releases to air and noise. Aircraft engines, will generate noise and emissions similar to those emitted from other fossil fuel combustion engines at ground level. The emissions give rise to environmental concerns regarding their global impact and their effect on local air quality at ground level. (ICAO, 2015).

5.2.2.2 Measures

Current practices in the oil and gas industry are assumed to have the following risk management measures in place (UNEP/O&G, 1997 and RPS Energy, 2015):

- Licences that may include (depending on the member state in which the activities occur) an obligation to apply environmental risk management measures in order to conduct oil or gas surveys, exploration and/or production;
- Review of the potential impact on environmental aspects and determination of the required risk management measures to prevent/minimise impacts (e.g. avoiding work that may disturb the breeding and migratory seasons for birds; measures to avoid disturbance to protected species and minimise the amount of areas cleared of vegetation; required materials and wastes storage) (Amec Foster Wheeler, 2015b);
- For noise abatement, current aircraft (i.e. aeroplanes and helicopters) are required to meet noise certification standards adopted by the ICAO (ICAO, 2015: Annex 16 - Aircraft Noise to the Convention on International Civil Aviation); and
- There is currently no specific EU legislation on aviation emissions but the general EU legislation establishing limit values for the pollutants of concern (i.e. NOx and particulates) apply at and around airports in the EU (European Commission, 2015). ICAO technical design standards limit emissions of NOx, carbon monoxide (CO) and unburned hydrocarbons (HFC) at source (ICAO, 2015). Limiting air emissions from any aviation used will depend on individual EU member states and future legislation.

5.2.2.3 Impacts

The risk levels for releases to air and noise from aircraft are presented in Table 5.2 taking into account the measures outlined above.

Table 5.2: Risk and impacts of ground investigations (aerial surveys)

Main Environmental Aspects	**Impacts**	**Risk Level**
Release to air (local air quality)	Based on the consumption of fuel, emissions to air would be expected from aircraft (ICAO, accessed 22 May 2015). Despite the potential impacts to air quality, the frequency of the occurrences will be minimal and therefore are generally considered to have low impact. (AFW O&G specialist)	4 low
Release to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate
Noise	Low flying aircraft over the study area may have sensitive receptors in the vicinity or could potentially cause very short term disturbance to migrating birds. (AFW O&G specialist)	4 low

Overall environmental risk characteristics of aerial surveys are considered low with respect to releases to air and noise impacts.

5.2.3 Geophysical testing/ investigations - seismic survey

5.2.3.1 Overview

Seismic surveys are required to define the spatial extent of stratified materials in the ground and characterise geology. Improper or insufficient surveying can affect the understanding of the relationship between geological processes and the flow of groundwater bodies. This would impact on approaches to protecting surface water or groundwater from possible contamination and over-exploitation during drilling activities (UK DECC, 2014). However, the methods adopted can give rise to environmental hazards relating to groundwater, surface water, releases to air, land-take, biodiversity impacts, noise, visual impact, induced seismicity and traffic.

Common to all seismic methods, a source is needed to create vibrations (sound waves) into the ground. Seismic lines may be created to cover the whole target area to enable to vibrator unit to survey. The generation of a vibration source and the activity required to lay geophones to record the seismic signal are what contributes to the impacts to the environment (IFC, 2007). Such impacts include: air emissions and noise from combustion engines of vehicles and vibration units/source, clearing of the land to access identified areas of interest and disturbance to local wildlife habitats.

5.2.3.2 Measures

Current practices in the oil and gas industry are assumed to have the following risk management measures in place (UNEP/O&G, 1997 and RPS, 2015):

- Required planning preparation and technologies suitable to the environment in place;
- Environmental impact assessment[30] carried out to:

[30] An EIA is only mandatory if the development is expected to produce more than 500t oil or 500,000m^3 gas per day. Projects below this threshold, for surface industrial installations for the extraction of petroleum and gas as well as for deep drillings, may require an EIA. The competent authority screens these projects to determine whether they are likely to have a significant adverse effect on the environment. In the event that the competent authority does not deem it necessary to conduct an EIA in order to grant the permit, then associated risk management measures may not be applied. However, this should be only for projects where environmental risk has been deemed to be low enough for these measures not be required.

    - Establish baseline environmental aspect conditions (e.g. air quality, noise, groundwater, surface water, ecology, landscape);
    - Review of the potential impact on environmental aspects and determination of the required risk management measures to prevent/minimise impacts (e.g. avoiding work that may disturb the breeding and migratory seasons for birds; measures to avoid disturbance to protected species and minimise the amount of areas cleared of vegetation; required materials and wastes storage); and
    - Establish monitoring measures for environmental aspects during operations.
- Traffic impact assessment taking account of noise, air emissions and other relevant impacts carried out and a transport management plan established;
- Fuel efficient generators and vehicles used, and regular maintenance of the vehicles and machines (Apache, 2008); and
- Further measures are as follow:
    - Required licences to conduct seismic surveys in place;
    - Required use of low impact seismic techniques or vibroseis where appropriate over shot hole method (dynamite) in non-soft soil areas if suitable for the area's land; and
    - Minimising land take and use of existing routes and already disturbed areas during the creation of access routes.

5.2.3.3 Impacts

The risk levels for seismic surveys are presented in Table 5.3.

Table 5.3: Risk and impacts of seismic surveys

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Intrusive surveys such as shotgun method (dynamite) may have an impact to surface from surface runoff. (UNEP/O&G, 1997) Impact in the event of a spill or release of potentially contaminative material from seismic machines and vehicle engines can lead to surface runoff to nearby surface water bodies. (UNEP/O&G, 1997) Site clearing from seismic activities may expose more land (UNEP/O&G, 1997) which would be more susceptible from surface run off in wet weather.	4 low
Releases to air (local air quality)	Dust and vehicle exhaust emissions will be emitted from vibroseis (WPC, 2015) or shot hole survey (Gibson&Rice, 2003). The latter method can generate a larger quantity of dust due to hole preparation. Otherwise generally gases such as carbon dioxide and nitrogen oxides emitted from engines and machinery and dust from vibrator movements during the survey can contribute to air emissions although generally in low quantities. (RPS, 2005 and Apache, 2008)	4 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate

Main Environmental Aspects	Impacts	Risk Level
Land take	Land and vegetation clearing and land acquisition to enable vibrator unit to survey the identified area. (UNEP/O&G, 1997) Damage to local infrastructure and archaeological sites (from vibrations) (WPC, 2015)	4 low
Biodiversity impacts	Seismic surveys could disturb flora and fauna where methods such as shot gun method (e.g. dynamite) is adopted. (UNEP/O&G, 1997) Improvements, creation or maintenance of access routes can potentially be responsible for geomorphologic damage or disturbance. Destabilising the soil structure during access road preparation (or by driving off-track) will expose the finer grained materials that are present beneath the surface layer, leading to scarring and increased erosion. (Appea, 2015)	2 low
Noise	Noise from vibroseis may involve sound Intensity & Pressure (dB re 1μPa at 1m) of about up to 255, <200Hz. Noise would be restricted to the immediate vicinity of the work in progress, stemming from vehicles and machinery. (Appea, 2015)	4 low
Traffic	Localised increase in traffic to site to perform investigative work.	4 low
Seismic	Shot hole drilling and testing or acoustic sources (vibrations, explosions) may generate disturbance to human and wildlife. (Gibson&Rice, 2003)	4 low

Risk to the environment from seismic activities are considered, generally, to be reasonably low. However, this may vary on a site-by-site basis. Based on how current land based seismic testing is carried out and due to the short term and transient nature of the activity, a low level of impact may be generally expected. Land clearing is required to enable the vibrator unit to survey the identified area, which can cause heightened impacts if in sensitive areas. If the project requires EIA then a land use and biodiversity impact assessment is typically carried out and measures to minimise impacts must be demonstrated to be in place before a licence is issued. If an EIA is not required then environmental impacts from seismic activities should have been screened and deemed insignificant by the competent authority. Therefore in both cases risks are generally expected to be controlled to an acceptable level.

5.2.4 Mobilisation of drilling rig and equipment and people to the drill location

5.2.4.1 Overview

Environmental impacts from this process are largely generated from fossil fuel combustion of vehicles and machinery. Transportation of drilling equipment and associated paraphernalia require access routes and areas of temporary storage. Environmental hazards relate to surface water, releases to air, noise and traffic impacts.

5.2.4.2 Measures

Employing risk management measures are similar to those listed for the 2.2 Geophysical testing/investigations process and technology:

Further measures include:

- Spill management procedure in place;
- Good construction practices including on-site housekeeping practices, such as keeping working areas tidy and clean, regularly removing waste materials and storing items safely);
- Installation of required emissions control devices on drilling and associated equipment. Engine and equipment use minimised to mitigate emissions to air (UNEP/O&G, 1997); and
- Specified planned transportation routes.

5.2.4.3 Impacts

Risk level for individual environmental aspects are presented in Table 5.4.

Table 5.4: Risk and impacts of mobilising drilling rig, equipment and people to drill location

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Water contamination from surface runoff or stormwater runoff. Impact in the event of a spill or release of potentially contaminative material from engines, spillages, leakages, sewage, camp grey water, etc. (UNEP/O&G, 1997) Vegetation cleared; possible erosion and changes in surface hydrology; emissions from earth moving equipment leading to potential disturbance of local population and wildlife. Potential long-term impacts from access route construction. (UNEP/O&G, 1997)	2 low
Releases to air (local air quality)	Dust emissions from use of dirt tracks. Exhaust emissions from vehicles and generators. (UNEP/O&G, 1997)	4 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate
Noise	Mobilisation would involve low level noise from camp activities therefore generating disturbance to local environment. This is considered short term and transient. Vibration and noise from earth moving equipment can lead to potential disturbance of local population and wildlife. Potential long-term impacts from access construction. (UNEP/O&G, 1997)	4 low
Traffic	Development of an oil and gas field would result in the need to construct and/or improve access roads and would result in an increase in industrial traffic. Overweight and oversized loads could cause temporary disruptions and could require extensive modifications to roads or bridges (e.g. widening roads or fortifying bridges). Increased traffic would also result in a potential for increased accidents within the project area. The locations at which accidents are most likely to occur are intersections used by project-related vehicles to turn onto or off of highways from access roads. Conflicts between industrial traffic and other traffic are likely to occur, especially on weekends and holidays. (UNEP/O&G, 1997)	4 low

Compared to construction and drilling activities, the impact and risk for mobilising drilling rig, equipment and people to the drill site may generally be considered to be low, since the scale of works is not as extensive. Impacts arise primarily from vehicles and machinery.

5.2.5 Site preparation (e.g. site clearing, accessibility, infrastructure, etc.)

5.2.5.1 Overview

Once the necessary permits are obtained, the identified site for well drilling will be cleared and prepared for exploration. Relevant environmental hazards relate to surface water, release to air, land take, visual impact, biodiversity, noise and traffic.

5.2.5.2 Measures

Employing risk management measures are similar to those listed for the process 2.2 Geophysical testing/investigations (UNEP/O&G, 1997 and RPS, 2015).

Further measures are as follow:

- Required licences to conduct oil or gas exploration and production phases in place;
- Establish monitoring measures for environmental aspects during operations;
- Site designed to avoid and contain spillages and leakages (IPIECA, 2013) such as: impervious site liner under pad with puncture proof underlay, double-skinned storage tanks, bunded tanks, tank level alarms, collection and control of surface run-off, oil-water separators in drainage and ensure access to spill kits (Amec Foster Wheeler, 2015b);
- Waste management plan for construction and operation in place; and
- Effective site security to ensure that the site is protected to prevent vandalism that may lead to pollution from damaged equipment/infrastructure.

5.2.5.3 Impacts

Table 5.5 presents the risks and impacts of site preparation.

Table 5.5: Risk and impacts of site preparation

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Soils compacted on existing roads, new access roads, and well pads generate more runoff than undisturbed sites. The increased runoff could lead to slightly higher peak storm flows into streams, potentially increasing erosion of the channel banks. (Tribal Energy, 2015) Impact in the event of a spill or release of potentially contaminative material from engines, spillages, leakages, sewage, camp grey water, etc. (UNEP/O&G, 1997)	4 low
Releases to air (local air quality)	Dust emissions from use of dirt tracks. Exhaust emissions from vehicles and generators. Dust generated from exposed land clearing and poor housekeeping practices. (UNEP/O&G, 1997)	4 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate

Main Environmental Aspects	Impacts	Risk Level
Land take	Site preparation will result in further vegetation clearing land uptake and acquisition for in preparation for site well pad. This can include possible community displacement to make way for exploration (Amec Foster Wheeler, 2015b)	8 moderate
Visual impact	Low level light from camp activities would be observed and therefore can disturb local environment. However this is considered short term during the exploration stage. (UNEP/O&G, 1997) The addition of wells, pipelines, access roads, and other ancillary facilities would result in an industrial landscape throughout the oil or gas field area. (Tribal Energy, 2015)	4 low
Biodiversity impacts	Surface disturbance, fragmentation or damage to ecological habitat is proportional to the total area of the site cleared prior to well pad construction. Vegetation and topsoil would be removed for the development of well pads, access roads, pipelines, and other ancillary facilities (UNEP/O&G, 1997). This would lead to a loss of wildlife habitat, reduction in plant diversity and potential for increased erosion. These access roads and seismic lines may pass through a variety of environments. The activities associated with the improvement, creation or maintenance of access routes are the main activities that can potentially be responsible for geomorphologic damage or disturbance. Destabilising the soil structure during access road preparation (or even by simply driving off-track) will expose the finer grained materials that are present beneath the surface layer, leading to scarring and increased erosion. (Appea, 2015)	4 low
Noise	Primary sources of noise during the drilling/development phase would be equipment (bulldozers, drill rigs, and diesel engines). Other sources of noise include vehicular traffic and blasting (blasting activities typically would be limited to areas where the terrain is hilly and bedrock shallow). (Tribal Energy, 2015) Vibration and noise from earth moving equipment can lead to potential disturbance of local population and wildlife. Potential long-term impacts from access construction. (UNEP/O&G, 1997)	4 low
Traffic	Access and footprint impact with increased number of vehicles accessing the site adding further traffic burden to local infrastructure if near any settlement. Mainly short-term with potential long-term impact from newly formed access. (UNEP/O&G, 1997)	4 low

Although environmental footprint for site preparation is considered larger than the other processes in stage 1 of oil and gas exploration, overall risk levels for site preparation are generally assessed to be reasonably low once risk management measures are implemented and adopted such as limiting the sources of air emissions (refer to sub-stage 3 - Mobilisation of drilling rig and equipment and people to the drill location).

However, land take is identified as generally presenting a moderate level of risk, as its impact is attributed to land clearing and preparation for vehicular and pedestrian traffic, construction and installation of facilities to make way for well drilling activities. Potentially, the land may be required for a considerable period of time depending whether, following the exploration phase, the site is deemed commercially viable and therefore moves into production phase. Impact would then be ongoing for the duration of the project lifetime and recovery of the land and natural habitats would be delayed (Halcrow, 2004). As a result, the same impact for land take is considered repeated across the subsequent processes and technologies, the assessment is conducted once here for the site preparation stage to cover the exploration and production stages.

5.3 Stage 2 Well design and construction and completion

5.3.1 Summary of environmental risks

In the well design and construction stage, the processes and technologies for well and rig construction, wildcat well drilling (drilling in areas where virtually very little is known about the subsurface geology and resource appraisal are carried out. Once the decision is made to turn a drilled well into a producing well, it must undergo well completion. The well completion steps which follows case installation include cementing, perforating, gravel packing and development of a production tree (or Christmas tree) installation (Rigzone, 2015).

The stage 2 processes include:

Sub-stage 4 Exploration well construction

a. Well pad construction
b. Rig installation
c. Drilling of vertical or deviated wells
d. Drill cuttings management
e. Cementing and casing
f. Well stabilisation

Sub-stage 5 Well testing

a. Well testing
b. Treatment of produced water from exploratory wells
c. Revised conceptual model and resource estimate
d. Reiteration of exploration activities
e. Assessment of the evaluated technical and economic viability

Sub-stage 6 Well completion

a. Well completion

The summary of risk characteristics for stage 2 Well design and construction are outlined in Table 5.6. Further details of the risk assessment can be found in Appendix A.

Table 5.6: Summary environmental hazards and risk level for stage 2 well design and construction

Processes/ technologies	**Environmental Aspects**	**Risk Characterisation (with** expected management measures in place)			**Risk Characterisation (without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
4. Exploration well construction							
4.1 Well pad construction	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Occasional	Minor	6 Moderate	Likely	Minor	8 moderate
	• Releases to air (local air quality)	Likely	Minor	8 Moderate	Likely	Minor	8 Moderate
	• Releases to air (contribution to global warming)	High Likely	Slight	5 Moderate	High Likely	Slight	5 Moderate
	• Biodiversity impacts	Occasional (short term definite)	Slight	3 low	Occasional (short term definite)	Minor	6 moderate
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
4.2 Rig installation	• Releases to air (local air quality)	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Noise	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Traffic	Likely	Slight	4 low	Highly Likely	Slight	5 moderate

4.3 Drilling of vertical or deviated wells	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Moderate	6 Moderate	Occasional	Major	12 high
	• Water resource depletion	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (local air quality)	Occasional	Minor	6 Moderate	Likely	Moderate	12 high
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Biodiversity impacts	Rare	Slight	2 low	Likely	Slight	4 low
	• Noise	Likely	Slight	4 low	Highly likely	Slight	5 moderate
	• Traffic	Likely (short term definite)	Slight	4 low	Highly likely	Slight	5 moderate
	• Groundwater contamination *(major accidental spills)*	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Surface water contamination *(major accidental spills)*	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Releases to air (local air quality and global warming) *(major accidental spills)*	Rare	Major	8 moderate	Occasional	Major	12 high
	• Impact to biodiversity *(major accidental spills)*	Rare	Catastrophic	10 high	occasional	Catastrophic	15 very high

	• Groundwater contamination *(minor accidental spills)*	Rare	Major	8 moderate	occasional	Major	12 high
	• Surface water contamination *(minor accidental spills)*	Rare	Major	8 moderate	occasional	Major	12 high
	• Releases to air (local air quality and global warming) *(minor accidental spills)*	Rare	Minor	4 low	Occasional	Moderate	9 moderate
	• Impact to biodiversity *(minor accidental spills)*	Rare	Major	8 moderate	occasional	Major	12 high
4.4 Drill cuttings management	• Groundwater contamination	Rare	Slight	2 low	Rare	Minor	4 low
	• Surface water contamination	Rare	Moderate	6 moderate	Occasional	Major	12 high
	• Releases to air (local air quality)	Occasional	Minor	6 moderate	Likely	Minor	8 moderate
	• Releases to air (contribution to global warming)	Likely	Slight	4 low	Likely	Minor	8 moderate
	• Traffic	Likely (short term definite)	Slight	4 low	Highly likely (short term definite)	Slight	5 moderate
4.5 Casing and cementing	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high

	• Surface water contamination	Rare	Moderate	6 Moderate	Occasional	Major	12 high
	• Releases to air (local air quality)	Likely	Slight	4 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Water resource depletion	Likely	Slight	4 low	Likely	Slight	4 low
4.6 Well Stabilisation	• Groundwater contamination	Rare	Moderate	6 Moderate	Rare	Moderate	6 Moderate
	• Surface water contamination	Rare	Minor	4 low	Rare	Minor	4 low
	• Releases to air (local air quality)	Likely	Minor	8 Moderate	Highly likely	Minor	10 high
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
5. Well testing							
5.1 Well testing	• Releases to air (local air quality)	Likely	Minor	8 Moderate	Likely	Minor	8 Moderate
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
5.2 Management of produced water from exploratory wells	• Groundwater contamination	Rare	Minor	4 low	Rare	Moderate	6 moderate
	• Surface water contamination	Rare	Minor	4 low	Rare	Moderate	6 moderate

	• Releases to air (local air quality)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Biodiversity impacts	Rare	Slight	2 low	Rare	Moderate	6 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
5.3 Revised conceptual model and resource estimate	Desk based task - no specific risk identified so not considered further.						
5.4 Assessment	Desk based task - no specific risk identified so not considered further.						
6. Well completion							
6.1 Well completion	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Slight	2 Low	Occasional	Minor	6 moderate
	• Releases to air (local)	Occasional	Slight	3 Low	Highly likely	minor	10 high
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 moderate	Highly likely	minor	10 high
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low

The list of processes and technologies assessed to have possible impact in stage 2 include:

- Well pad construction;
- Rig installation;
- Drilling of vertical or deviated wells;
- Cementing and casing;
- Exploratory well;
- Well testing;
- Treatment of produced water from exploratory wells; and

- Well completion.

The following sections provide discussion and outline relevant environmental hazard impacts for the identified list of processes and technologies in further detail.

5.3.2 Well pad construction

5.3.2.1 Overview

Activities from constructing a well pad would involve excavation work, laying of pad liners and concrete platforms and installation of other supporting facilities such as roads, pipelines and storage facilities. These activities will affect the area due to clearing and exposing the land thereby increasing the risk of surface runoff containing suspended solids into nearby water bodies and dust emissions to air in dry conditions. The site is industrial in nature with ongoing vehicle and construction movements contributing to disturbance and potential impacts on fauna, flora and local communities.

Heavy machinery and installations in preparation for exploration drilling will give rise to exhaust emissions (particulates, oxides of nitrogen, carbon monoxide, sulphur dioxide and volatile organic compounds (VOCs)). Nitrogen oxides and VOCs may combine to form ground-level ozone.

5.3.2.2 Measures

Similar to previous stages, measures to mitigate environmental risk assumed to be applied during this stage include (UNEP/O&G 1997 and RPS, 2015):

- Required licences that may include (depending on the member state in which the activities occur) an obligation to apply environmental risk management measures in order to conduct oil or gas surveys, exploration and/or production[31];
- Environmental impact assessment[32] (EIA) carried out to:
    - Establish baseline environmental aspect conditions (e.g. air quality, noise, groundwater, surface water, ecology, landscape);
    - Review of the potential impact on environmental aspects and determination of the required risk management measures to prevent/minimise impacts (e.g. avoiding work that may disturb the breeding and migratory seasons for birds; measures to avoid disturbance to protected species and minimise the amount of areas cleared of vegetation; required materials and wastes storage); and
    - Establish monitoring measures (refer to 2.4.1.2 –licensing) for environmental aspects during operations.
- Waste management plan for construction and operation in place;
- Spill management procedure in place;
- Traffic impact assessment taking account of noise, air emissions and other relevant impacts carried out and a transport management plan established;

[31] As set out under the EU's Prospection, Exploration and Production of Hydrocarbon Directive.

[32] An EIA is only mandatory if the development is expected to produce more than 500t oil or 500,000m^3 gas per day (Directive 2011/92/EU as amended by 2014/52/EU). For projects below this threshold, for surface industrial installations for the extraction of petroleum and gas as well as for deep drillings, the competent authority screens these projects to determine whether they are likely to have a significant adverse effect on the environment. In the event that the competent authority does not deem it necessary to conduct an EIA in order to grant the permit, then associated risk management measures may not be applied. However, this should be only for projects where environmental risk has been deemed to be low enough for these measures not be required.

- Installation of required emissions control devices on drilling and associated equipment. Engine and equipment use minimised to mitigate emissions to air (UNEP/O&G, 1997);
- Fuel efficient generators and vehicles used, and regular maintenance of the vehicles and machines (Apache, 2008);
- Effective site security to ensure that the site is protected to prevent vandalism that may lead to pollution from damaged equipment/infrastructure;
- Further measures are as follow:
    - Site designed to avoid and contain spillages and leakages (IPIECA, 2013) such as: impervious site liner under pad with puncture proof underlay, double-skinned storage tanks, bunded tanks, tank level alarms, collection and control of surface run-off, oil-water separators in drainage and ensure access to spill kits;
    - Good construction practices for preventing dust, leaks and spills (i.e. good on-site housekeeping practices such as keeping working areas tidy and clean, regularly removing waste materials and storing items safely);
    - Minimising land take and use of existing routes and already disturbed areas during the creation of access routes;
    - In construction areas, appropriate cover of dusty construction materials; and
    - Consideration of decommissioning and restoration in site selection and preparation (UNEP/O&G, 1997).

5.3.2.3 Issues

The risk levels for well pad construction are presented in Table 5.7.

Table 5.7: Risk and impacts of well pad construction

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Poor management practices during construction may have the potential for contaminants to be released into groundwater which is dependent on the depth to groundwater and the permeability of the intervening material. (UNEP/O&G, 1997 and Appea, 2015)	6 Moderate
Surface water contamination	Contamination and soils compacted on construction site can generate surface runoff if not appropriately managed. This increased runoff could lead to slightly higher peak storm flows into streams, potentially increasing pollution impact to surface water bodies.	6 Moderate
Releases to air (local air quality)	Dust emissions from exposed construction materials. Exhaust emissions from vehicles and generators and poor housekeeping practices during construction	8 Moderate
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate
Biodiversity impacts	Low level lighting at night and disturbance of fauna and impacts on flora from construction activities. (UNEP/O&G, 1997)	3 low
Visual impact	The well pad construction and associated activities would introduce an industrial site for oil or gas exploration. (Tribal Energy, 2015)	4 low

Main Environmental Aspects	Impacts	Risk Level
Noise	Disturbance of local residents and fauna by noise from generators, machinery and vehicles. (Halcrow, 2004) Increased traffic will be expected contributing to further background noise. (UNEP/O&G, 1997)	4 low
Traffic	Traffic from increased number of construction vehicles.	4 low

With adequate risk management measures in place, environmental hazards of well pad construction may generally be considered to be relatively low. However risks to groundwater, surface water and air are expected to be moderate, due to their potentially more significant consequences. The risk of air releases are also deemed generally moderate, but impacts would depend upon the amount, duration, location, and characteristics of the emissions and the meteorological conditions (e.g. wind speed and direction, precipitation, and relative humidity) (Morris, 2005).

5.3.3 Rig installation

5.3.3.1 Overview

Once the well pad is in place, the drilling rig is installed. Compared to well pad construction, there are fewer environmental hazards associated with rig installation. The main impact would be releases to air, noise and traffic which are attributed to vehicles and machines transporting the rig either in modules or as a whole, onto the site.

5.3.3.2 Measures

Measures outlined in stage 1 site identification and preparation and for the process 4.1 well pad construction are also applicable for rig installation.

5.3.3.3 Issues

The risk levels for release to air, noise and traffic for rig installation are presented in Table 5.8.

Table 5.8: Risk and impacts of rig installation

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	Dust emissions from exposed construction materials, exhaust emissions from vehicles and generators (Halcrow, 2004) and poor housekeeping practices during construction (RPS, 2005)	4 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality; the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate
Noise	Noise from increased traffic and vehicle operating on site (Tribal Energy, 2015) for the installation of the rigs. More transportation activity is expected if the rig in constructed in modules.	4 low
Traffic	Vehicles to transport the rig part(s) and equipment on site.	4 low

Overall environmental risk characteristics of rig installation are generally considered relatively low with respect to releases to air, noise and traffic impacts.

5.3.4 Drilling of vertical or deviated wells

5.3.4.1 Overview

Well drilling requires the use of large and heavy machinery powered by generators. Noise and emissions to air from the engines will occur. Drilling typically operates continuously over a period of time resulting in noise and light pollution.

The drilling process will also generate mud cuttings which may be contaminated with drilling fluids (oil based mud or NADF). These are filtered out of the drilling fluid system before it is disposed of. Rendering drill cuttings or NADF non-hazardous may utilise treatment methods which include thermal desorption (TDU) to prepare NADF for re-use, bioremediation, or solidification with cement and/or concrete (IFC, 2007). These methods are likely to contribute to emissions to air and require storage of chemicals which presents a risk of accidental chemical spillages or leakages.

Any gas or VOCs that are released from the sediment during drilling may be flared if insufficient quantities are captured (i.e. green completions). Although the need for flaring may not be frequent, flaring and emissions from associated transportation would contribute to releases to air impacting air quality.

Incidents such as rig explosions and well blowout can occur during drilling. These can have immediate adverse effect on the environment and surrounding areas such as plumes of groundwater pollution, oil spillages leaking into surface water bodies and gas releases into the air. Risks and impacts associated with these kinds of accidental spills apply to both drilling and production (stages 2 & 3) of the onshore lifecycle. Therefore, the risks and impacts considered for both major and minor accidental events in section 5.4.6 also apply here.

5.3.4.2 Measures

Outlined for stage 1 site identification and preparation and for 4.1 well pad construction, the general measures also apply for drilling. Measures for controlling accidental risks from drilling are covered in section 5.4.6 (site operations). Further measures assumed for drilling are:

- Well safety controls and monitoring deployed[33]. Depending on member states' requirements, well operators may have a legal duty to manage and control risks to people. In addition to being generally applied in conventional oil and gas activities, these measures are also generally applied in unconventional wells[34];
- Water requirement assessed and treated or produced water reused; and
- Install noise screening such as noise barrier/enclosure.

5.3.4.3 Issues

The risk levels for well pad construction are presented in Table 5.9.

[33] Based on Amec Foster Wheeler (2014) Such examples include blowout preventers to reduced risk of uncontrolled flow from the reservoir to the surface, monitoring and shut down systems, various detection systems for fire or gas leakages (IFC, 2007), continuous monitoring for leaks and release of gas and liquids, isolate underground source of drinking water prior to drilling, ensure micro-annulus is not formed, casing centralizers to centre casing in hole, select corrosive resistant alloys and high strength steel, fish back casing, maintain appropriate bending radius, triple casing, isolation of the well from aquifers.

[34] As an example from the UK, regulation particularly under hydraulic fracturing operations would have the HSE monitor well operations to check that relevant legal duties are carried out. Inspection would be inspected jointly with the Environment Agency or Scottish Environmental Protection Agency during the exploratory phase. The relevant environmental regulator will monitor the environmental impacts and inspect the operator's reports. The greater the potential risk, the greater the scrutiny by environmental regulators. Conditions attached to permits will set out the minimum level of site-based monitoring and reporting. Planning authorities are responsible for enforcing any conditions attached to the planning permission. For example, this may include monitoring of noise or dust levels. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283834/Regulation_v3.pdf

Table 5.9: Risk and impacts of drilling of vertical or deviated wells

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	There may be leakages from subsurface formations if well casing and (triple) cement do not fully seal the well. Aquifers can be impacted by other non-potable formation waters seeping out. In addition, the well may provide a path for surface contaminants (e.g. drilling fluids, chemicals, drill cuttings) to come into contact with groundwater. Inadequate housekeeping practices on a site can lead to leaks, improper storage facilities and increased risk of spills (Haliburton, 2012).	6 Moderate
Surface water contamination	Drilling and well development often remove large quantities of water that is held in the same formation as the hydrocarbons. This is referred to as produced water. The generation of produced water can create several problems: • Exploratory wellbores may decrease the pressure in water wells and affect their quality; • Produced water that is saline or contaminated with drilling fluids can contaminate soils or surface waters, if not correctly managed; and • Produced water may also contain organic acids, alkalis, diesel oil, crankcase oils, and acidic stimulation fluids (e.g. hydrochloric and hydrofluoric acids). (Tribal Energy,2015) Insufficient treatment of produced water can result in contamination of surface water (if discharged to surface water). Produced water is currently managed through processes such as recycling, reinjection into the original formation or an alternative formation with suitable containment properties (with pre-treatment only to increase injectivity), treatment and discharge, evaporation or infiltration (IFC, 2007). Leakage or discharge of drainage water may result in pollution of groundwater (UNEP/O&G, 1997). In the event of a spillage during well drilling or testing, produced water may leak into surface water bodies and contaminate them. Depending on the geology of the area, the characteristics of produced water may vary. Produced water may contain salt, oil and grease, various inorganic and organic chemicals and naturally occurring radioactive material (NORM). (DECC, 2014)	6 Moderate
Water resource depletion	Depletion of water resources will depend on the scale of drilling required. Increased pressure on localised water resources may result; however this effect is expected to be small due to the small scale activity of the exploration stage (Haliburton, 2012).	4 low
Releases to air (local air quality)	Release of trapped gas, VOCs, dust from drilling and emissions from flaring of gas or oil (RPS, 2005). Principal pollutants emitted from oil production include nitrogen oxides, sulphur oxides, carbon monoxide and particulates. Additional pollutants can include: hydrogen sulphide (H_2S); volatile organic compounds (e.g. methane	6 Moderate

Main Environmental Aspects	Impacts	Risk Level
	and ethane), benzene, ethyl benzene, toluene and xylenes (BTEX), glycols and polycyclic aromatic hydrocarbons (Shell, 2011). Dust emissions from exposed construction materials, exhaust emissions from vehicles and generators (Halcrow, 2004).	
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change. Whereas past data have indicated that emissions from exploration and production activities can contribute up to 1% of global CO2 emissions (UNEP/O&G, 1997), according to a report conducted by Rhodium Group (Larsen et al, 2015), the best currently available data show that around 3.6 trillion cubic feet (Tcf) of natural gas escaped into the atmosphere in 2012 from global oil and gas operations. Methane escaping from oil and gas operations was estimated to approximately 1,680 million metric tonnes of carbon dioxide equivalent (MtCO2e) in 2012 (Larsen et al, 2015).	5 Moderate
Biodiversity impacts	Risks to habitats and species due to drilling and associated activities disturbing the natural environment. Contaminating substances associated with drilling fluids and petroleum products may leak and soil contamination from these sources can be widespread and persistent but generally localised in the immediate vicinity of drilling and production activity. Contamination can be variable depending on methods and materials used and the occurrence of isolated spills and materials misuse.	2 low
Noise	The highest noise levels would occur from drilling and the flaring of gas. Drilling noise would occur continuously for a period of time depending on the depth of the formation. Exploratory wells that become production wells would continue to generate noise during the production phase (Amec Foster Wheeler, 2015b).	4 low
Traffic	An overall increase in heavy truck traffic would accelerate the deterioration of roads, requiring local government agencies to schedule road repair or replacement more frequently than under the existing traffic conditions. Increased traffic would also result in a potential for increased accidents within the project area. The locations at which accidents are most likely to occur are intersections used by project-related vehicles to turn onto or off of highways from access roads. Conflicts between industrial traffic and other traffic are likely to occur, especially on weekends, holidays, and seasons of high use by recreationists. (Tribal Energy, 2015).	4 low

Generally, environmental risk from oil and gas drilling operations is considered moderate for groundwater, surface water and emissions to air (local and globally).

5.3.5 Drill cuttings management

5.3.5.1 Overview

Ways in which drill cuttings are managed onshore may include: reuse – cleaned drill cuttings for road construction material and hard standing; biological treatment such as land farming, land-treatment or composted provided the type of oil use is biodegradable; underground injection (annular injection); and burial such as pits on a temporary or permanent basis (OGP, 2009). Waste burial can be considered acceptable, once the associated risks have been assessed and provisions have been made for closure and aftercare (including records of location and content).[35]

Drill cuttings is defined as waste under Article 3(1) of the Mining Waste Directive by reference to Article 3(1) of the Waste Framework Directive 2008/98/EC.

5.3.5.2 Measures

- Waste management plan for operation (English Environment Agency, 2010) including:
    - Drill cuttings separated from the drilling mud and collected in skips and taken offsite as soon as reasonably practicable for recycling or recovery by an authorised waste contractor;
    - Containers of drilled cuttings should not be over filled and precautions taken to prevent spillage;
    - All waste collection areas and deposit and storage of oil based drilling muds will have a secondary containment;
    - Continuous supervision of the cuttings skips when active mud management is in operation;
    - Segregation of oil based mud contaminated cuttings; and
    - Segregation of cuttings contaminated with hydrocarbons from the formation encountered.
- Spill management procedure in place;
- Hazardous chemicals stored in designated areas with bunding and drain systems to contain leaks;
- Chemical selection procedure prioritising:
    - Lowest toxicity;
    - Lowest persistence; and
    - Lowest bioaccumulation potential.

5.3.5.3 Issues

The risk levels for drill cutting management are presented in Table 5.10.

Table 5.10: Drill cutting management

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Poor construction practices for drill cutting storage or disposal may have the potential for contaminants such as chemicals, additives and oil contaminant to be released into groundwater through long-term seepage. This is very much dependent on the depth to groundwater and the permeability of the intervening material.	2 low

35 www.ogp.org.uk/pubs/413.pdf

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Poor storage and/or disposal of contaminated drill cuttings (likely contaminated with oil based muds, chemicals and additives used for drilling operations, etc.) on site can generate surface runoff if not appropriately managed. This increased runoff could lead to higher peak storm flows into streams, potentially increasing pollution impact to surface water bodies.	6 Moderate
Releases to air (local air quality)	Air and dust emissions from exposed storage of drill cuttings. Exhaust emissions from vehicles and generators and poor housekeeping practices.	6 Moderate
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	4 low
Traffic	Traffic from increased number of waste management vehicles.	4 low

With adequate risk management measures in place such as a comprehensive waste management plan, environmental hazards are generally low. However risks to surface water and air are judged generally moderate. Impacts would depend upon the storage, treatment and disposal method of the drill cuttings. Otherwise, amount, duration, location, and characteristics of the emissions and the meteorological conditions (e.g. wind speed and direction, precipitation, and relative humidity) would typically vary the impact on the environment (Morris, 2005).

5.3.6 Cementing and casing

5.3.6.1 Overview

Proper installation of casing is key to mitigating environmental risks. Inadequate casing can lead to drilling fluid, chemicals or hydrocarbon seepage and leakage into groundwater or surface water bodies. Wet cement may contaminate the groundwater or surface water bodies from spillages. Improper casing installation can also compromise pressure control in the well, which in extreme cases can lead to a catastrophic blowout of well fluids.

5.3.6.2 Measures

As outlined for stage 1 (site identification and preparation) and for the process of well pad construction, general risk management measures are assumed to be in place for casing. Further measures assumed for casing installation are:

- Calcium chloride used in cement applications which accelerates the setting of cement (Michaux, 2005); and
- Integrity testing of wells to ensure proper construction and containment. Integrity testing of wells is expected to be widely practiced. However, in terms of independently reviewed testing of well integrity, although this may be stipulated as part of the oil and gas operation plan, it is not indicated as a mandatory practice for all member states. For the UK, there are Well Integrity[36] Guidelines which were

[36] http://oilandgasukenvironmentallegislation.co.uk/contents/Tables/Welltest_table.htm

issued in July 2012 together with existing guidelines for the suspension and abandonment of wells which cover the entire life cycle of the well[37].

5.3.6.3 Issues

The risk levels for casing installation are presented in Table 5.11.

Table 5.11: Risk and impacts of casing installation

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Ineffective casing due to poor cement job or damage to the casing may have an impact on groundwater. The circulation of cement on production casing prevents monitoring of the space between the casing strings for changes in pressure which could indicate leakage through the casing or cement sheath (FracFocus, 2015). There are examples of steel and plastic casings widely used due to high resistance to corrosion. However groundwater reaction to steel casing can potentially raise the pH of the water. Sources of issues include: • Chemical attack on the casing material; • Sorption and desorption; • Leaching of the casing material; and • Microbial colonisation and attack. (US EPA, 1991) If a well is completed improperly such that subsurface formations are not sealed off by the well casing and cement, aquifers could be impacted by migration of formation water into aquifers along the well (Haliburton, 2012).	6 Moderate
Surface water contamination	The interaction between surface water and groundwater may also be affected if the two are hydrologically connected, potentially resulting in unwanted dewatering or recharging and impacts on surface water (Haliburton, 2012).	6 Moderate
Releases to air (local air quality)	Emissions from vehicles and machines can be expected. Impact would depend on the duration of the cementing work.	4 low
Releases to air (contribution to global warming	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate
Water resource depletion	Use of water for water based fluid during drilling and during cementing application may have some impact on the local water resource.	4 low

With risk management measures in place impacts to groundwater and surface water are judged to generally be moderate as, although the likelihood of the impact occurring for groundwater and surface water is 'rare', the consequence is 'high'

[37] https://www.gov.uk/government/publications/government-response-to-an-independent-review-of-the-regulatory-regime

reflecting the difficulty in remediating contaminated land, groundwater and water bodies.

In general few data exist in the public domain for the failure rates of onshore wells in Europe. Nonetheless, it is thought that well barrier failure can and will occur in a small number of wells and this could in some instances lead to environmental contamination. In addition, some wells in the UK and Europe will become "orphaned" (well with no responsible party) in the future. It is important therefore that the appropriate financial and monitoring processes are in place, particularly after well abandonment.[38]

5.3.7 Well stabilisation

5.3.7.1 Overview

Once the well reaches oil and/or gas reservoirs, the exploratory well begins to achieve hydrocarbon flow, at which point the well is then plugged. A temporary flare system as opposed to a centralised permanent system (for production wells) will typically be installed. Release to air from flaring may impact air quality. If resources are located that are viable, a wellhead valve is installed.

5.3.7.2 Measures

As outlined for stage 1 site identification and preparation and for the process of well pad construction, these measures are also assumed to be applied for well stabilisation. Further assumed measures for well stabilisation are (Amec Foster Wheeler (2015b): Flares to reduce emissions from venting at exploration stage (where not connected to gas network or a green completion system)

5.3.7.3 Issues

The risk levels for well stabilisation are presented in Table 5.12.

Table 5.12: Risk and impacts of well stabilisation

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Exploratory well bores may provide a path for surface contaminants to come into contact with groundwater or for waters from subsurface formations to co-mingle. (Tribal Energy, 2015)	6 Moderate
Surface water contamination	Exploratory well bores may provide a path for surface contaminants to come into contact with waters from subsurface formations to commingle.	4 low
Releases to air (local air quality)	Flaring of any trapped gas or emission of VOCs, dust, from exploratory well.	8 Moderate
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate

[38] https://duke.pure.elsevier.com/en/publications/oil-and-gas-wells-and-their-integrity-implications-for-shale-and-

5.3.8 Well testing

5.3.8.1 Overview

During well testing (for productivity, fluid properties, composition, flow, pressure and temperature), the main environmental aspects would be releases to air from flaring.

5.3.8.2 Measures

As outlined for stage 1 site identification and preparation and for the process of well pad construction, the measures related to releases to air are also applied for well testing.

5.3.8.3 Issues

The releases to air risk level for well testing are presented in Table 5.13.

Table 5.13: Risk and impacts of well testing

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	Flaring of any trapped gas or emission of VOCs, dust, from exploratory well. (UNEP/O&G, 1997)	8 Moderate
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change. However the overall effects are likely to be slight.	5 Moderate

The main impact, release to air, is expected to generally be moderate in risk level due to flaring during well testing.

5.3.9 Management of produced water from exploratory wells

5.3.9.1 Overview

Environmental impact from accidental leakage or spillages of produced water can lead to contaminated soils, surface water or over longer periods, groundwater. Produced water may contain (Oil & Gas UK, 2015b):

- Organic acids, alkalis, diesel oil and crankcase oils;
- Chemicals added to assist the process;
- Dissolved minerals such as chloride and sodium as well as iron and other metals (e.g. acidic stimulation fluids (e.g., hydrochloric and hydrofluoric acids)); and
- Naturally occurring radioactive minerals (NORM).

5.3.9.2 Measures

As outlined for stage 1 site identification and preparation and for the process of well pad construction, the general measures are also applied for management of produced water. Specific management approaches may include (following the required treatment) recycling, discharge to water course, evaporation, infiltration or deep well injection (IFC, 2007). For deep well injection, only minimal treatment is conducted to ensure that particles in the produced water do not block the formation and reduce its capacity.

5.3.9.3 Issues

The risk levels for management of produced water from exploratory wells are presented in Table 5.14.

Table 5.14: Risk and impacts of treatment of produced water from exploratory wells

Main Environmental Aspects	**Impacts**	**Risk Level**
Groundwater contamination	In the event of a spillage produced water may leak into groundwater water bodies	4 low
Surface water contamination	Potential leakage to surface water bodies of produced water containing contaminants such as salt, oil and grease, various inorganic and organic chemicals and NORM. Produced water is currently managed, through processes such as recycling, treatment and discharge, evaporation or infiltration, and deep well injection (IFC, 2007). Impact could arise from inadequate management of produced water such as overflows from storage tanks, improper disposal and accidental release of untreated produced water from tanks. If stored and treated appropriately, the risk is minimal. (COGA, 2011 and IPIECA, 2015)	4 low
Releases to air (local air quality)	Any VOCs or light hydrocarbons contained in the produced water may be released into the atmosphere. Impact is not considered significant if concentrations are minimal. (UNEP/O&G, 1997)	2 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate
Biodiversity impacts	Land contaminated by produced water may change the characteristics of the sediment and therefore will impact biodiversity. Produced water may contain high salt, oil and grease, chemicals and NORM all of which have the potential to adversely affect local fauna and flora. (DECC, 2014)	2 low
Noise	Noise from power generator and treatment facility	4 low
Traffic	Some traffic would be generated from transportation of produced water for storage or for treatment. The amount of produced water varies greatly depending on the formation. Typical water cut ranges from 25% or lower at the start of production (1 barrel of water produced per 3 barrels of oil) to 75% or higher later in production (3 barrels of water produced per 1 barrel of oil).	4 low

A relatively low risk level is generally expected from the management of produced water with expected risk management measures in place.

5.3.10 **Well completion**

5.3.10.1 Overview

The commencement of the completion process may depend on the type and design of well. Drilling of the well cuts through rock formation and into the reservoir below and the exposed sides of the well cannot support themselves, hence, casing is installed whilst the well is being drilled. The well completion steps following case installation such as cementing, perforating, gravel packing and development of a production tree installation (Rigzone, 2015) and completion fluids can result in environmental impacts. In a conventional well completion, the 'flowback' period (also known as well clean up) may involve flaring or venting of gas to the atmosphere, unless a green completion or reduced emissions completion (REC) is used (IPIECA, 2015).

5.3.10.2 Measures

Measures assumed to be in place are as described in stage 1 and 2. Measures specific to well completion are:

- Installation of required emissions control devices on drilling and associated equipment. Engine and equipment use minimised to mitigate emissions to air (UNEP/O&G, 1997);
- Good construction practices for preventing dust, leaks and spills (i.e. good on-site housekeeping practices such as including keeping working areas tidy and clean, regularly removing waste materials and storing items safely);
- Deployment of key elements to maintain well safety[39];
- Mixing cement only at the point of use and reviewing previous well operations to estimate required amount of cement. Keeping the required cement to a minimum to avoid excess (Ythan, 2014, Ffyne, 2014, Mariner, 2012, and Kew, 2012);
- Appropriate flare tip design and deployment of appropriate equipment and maintenance;
- Recycling completion fluids through well as a closed loop system with appropriate emergency shutdown systems, and assemblies (i.e. Christmas tree valves); and
- Gas capture during well completions as part of Green Completions or Reduced Emissions Completions (RECs) (IPIECA, 2015)[40].

5.3.10.3 Issues

The risk levels for well completion are presented in Table 5.15 taking into account the measures outlined above.

Table 5.15: Risk and impacts of well completion

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	There is a potential for leakage from subsurface formations if well casing and (triple) cement do not fully seal the well. Groundwater aquifers can be impacted by other non-potable formation waters seeping out. (Tribal Energy, 2015) Accidental leakage of completion fluids (e.g. corrosion inhibitor, biocide, oxygen scavenger) through inadequate well completions. (Amec Foster Wheeler, 2015b)	6 Moderate
Surface water contamination	Leaks from insufficient well completion works can lead to contamination of surface water bodies. (Tribal Energy, 2015) Accidental discharge of completion fluids (e.g. corrosion inhibitor, biocide, oxygen scavenger) resulting from loss of containment (Amec Foster Wheeler, 2015b)	2 Low

[39] Such as blowout preventers, pressure & temperature monitoring and shutdown systems, fire and gas detection and continuous monitoring for leaks and release of gas and liquids, isolate underground source of drinking water prior to drilling, ensure micro-annulus is not formed, casing centralizers to centre casing in hole, select corrosive resistant alloys and high strength steel, fish back casing, maintain appropriate bending radius, triple casing, isolation of the well from aquifers.

[40] IPIECA, Accessed 30 April 2015
Mobile equipment is brought temporarily to the well site to separate gas from the liquids and solids in the follow back stream, producing a gas stream that is ready or nearly ready for the sales pipeline

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	Flaring or venting of gas to the atmosphere. (IPIECA, 2015 and BP, 2013(a)). Fugitive emissions of methane and other trace gases from routing gas generated during completion via small diameter pipeline to the main pipeline or gas treatment plant. (AEA, 2012).	3 Low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate
Noise	Potential impact but installation of completed items for the well is expected to be short and transient.	4 low

If appropriate risk management steps are taken, impacts associated with well completion are generally judged to be low. Although incidents may be considered rare with assumed risk management practices in place, the consequence of leakages and contamination particularly into groundwater would be a moderate risk.

5.4 Stage 3 Development and production

5.4.1 Summary of environmental risks

When an area has been explored and following appraisal is assessed to be economically viable, preparations are made to develop the well into a production well. The process and technologies required range from planning and design of the site, further construction and permanent installation of facilities and equipment, hook-up and commissioning of the production well and drilling of further wells in the field. The processes and technologies for stage 4 are as follows:

Sub-stage 7 Field development design

a. Field development

Sub-stage 8 Construction and installation

a. Implementation of development plan

Sub-stage 9 Hook-up and commissioning

a. Well commissioning
   - Hook-up;
   - Pre-commissioning (integrity and production testing of the well); and
   - Commissioning (testing of hydrocarbon production).

Sub-stage 10 Development drilling - drilling of small or large field

a. Processes and technologies for production takes into account the production of hydrocarbons and also the process, utilities and waste treatment systems.

Sub-stage 11 Hydrocarbon production – hydrocarbon production and processing

a. Crude oil and gas processing

b. Site operations

c. Well workover

d. Process treatment systems

e. Utility systems

f. Waste Handling

g. Hydrocarbon offtakes

h. Enhanced recovery (water flooding)

i. Enhanced recovery (substance injection)

j. Well stimulation (low volume HF)

The summary of risks for stage 4 Development and Production are outlined in Table 5.16. Further details of the risk assessment can be found in appendix A.

Table 5.16: Summary environmental hazards and risk level for stage 4 development and production

Processes/ technologies	Environmental Aspects	Risk Characterisation (with expected management measures in place)			Risk Characterisation (without expected management measures in place)		
		Likelihood	Consequence	Risk	Likelihood	Consequence	Risk
7. Field development design							
7.1 Field development: - Field development concept - Front end engineering design - Detailed design	Desk based task - no specific risk identified so not considered further.						
8. Construction and installation							
8.1 Implementation of development plan	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Land take	Likely	Moderate (wider scale)	12 High	Likely	Moderate (wider scale)	12 High

	• Biodiversity impacts	Rare	Slight	2 low	Occasional	Slight	3 low
	• Visual impact	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Noise	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low
	• Traffic	Likely (short term definite)	Slight	4 low	Likely (short term definite)	Slight	4 low
9. Hook-up and commissioning							
9.1 Well commissioning - Well hook-up - Pre-commissioning - Commissioning	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Occasional	Slight	3 low	Likely	Slight	4low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Water resource depletion	Rare	Slight	2 low	Rare	Slight	2 low
	• Biodiversity impacts	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
10. Development drilling – if required, once field development in place							
10.1 Development drilling (further development, if required)	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Moderate	9 high
	• Releases to air (local air quality)	Occasional	Slight	3 low	Likely	Slight	4 low

	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Water resource depletion	Likely	Slight	4 low	Likely	Slight	4 low
	• Land take	Highly likely	Minor	10 high	Highly likely	Minor	10 high
	• Biodiversity impacts	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Noise	Likely	Slight (Temporary)	4 low	Highly likely	Slight	5 moderate
	• Visual impact	Highly likely	Moderate	15 Very high	Highly likely	Moderate	15 Very high
	• Traffic	Likely	Slight	4 low	Highly likely	Slight	5 moderate
11. Hydrocarbon production – Hydrocarbon production and processing							
11.1 Crude oil & gas processing Operation of plant and process equipment and maintenance activities[41]	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Moderate	9 high
	• Releases to air (local air quality)	Occasional (Periodic)	Minor	6 Moderate	Likely (periodic)	Moderate	10 high
	• Releases to air (contribution to global warming)	Occasional (Periodic)	Moderate	9 high	Likely	Moderate	12 high
	• Noise	Occasional	Slight	3 low	Likely	Slight	4 low
	• Traffic	Likely (periodic)	Slight	4 low	Likely (periodic)	Slight	4 low

[41] For oil, this is a typical three phase separation: oil, gas and water.

11.2 Site operations - Major accidental spillages of fluids related to platform operations	• Groundwater contamination	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Surface water contamination	Rare	Catastrophic	10 high	Occasional	Catastrophic	15very high
	• Releases to air (local air quality and global warming)	Rare	Major	8 moderate	Occasional	Major	12 high
	• Impact to biodiversity	Rare	Catastrophic	10 high	occasional	Catastrophic	15 very high
11.2 Site operations - minor accidental spillages of fluids related to platform operations	• Groundwater contamination	Rare	Major	8 moderate	occasional	Major	12 high
	• Surface water contamination	Rare	Major	8 moderate	occasional	Major	12 high
	• Releases to air (local air quality and global warming)	Rare	Minor	4 low	Occasional	Moderate	9 moderate
	• Impact to biodiversity	Rare	Major	8 moderate	occasional	Major	12 high
11.3 Well workover – Conducted during monitoring and maintenance of completed wells.	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
11.4 Process treatment systems - Produced water collection and management	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Moderate	9 high

	• Releases to air (local air quality)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (contribution to global warming)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
11.5 Utility systems - Wastewater and sewage collection and treatment	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (contribution to global warming)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
11.6 Waste handling - Waste handling, storage, collection and transport	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Occasional	Slight	3 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Occasional	Slight	3 low	Likely	Slight	4 low
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low

11.7 Hydrocarbon offtakes - product export, pipelines / road tankers within the production process boundary.	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Rare	Slight	2 low	Likely	Slight	4 low
	• Releases to air (contribution to global warming)	Highly Likely	Slight	5 Moderate	Highly likely	Minor	10 high
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
11.8 Enhanced recovery (Water flooding) – water injection to sweep field and boost production.	• Releases to air (local air quality)	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (contribution to global warming)	Minor	Rare	3 low	Minor	Rare	3 low
	• Water resource depletion	Minor	Rare	4 low	Minor	Occasional	6 moderate
	• Land take	Minor	Likely	8 moderate	Minor	Highly Likely	9 high
	• Noise	Slight	Occasional	4 low	Minor	Occasional (short-term definite)	6 moderate
	• Visual impact	Slight	Rare	2 low	Slight	Rare	2 low
	• Seismic (induced seismicity)	Slight	Rare	2 low	Slight	Rare	2 low
	• Traffic	Slight	Occasional	4 low	Slight	Highly likely	5 moderate
11.9 Enhanced recovery (substance injection) – steam / miscible gas / polymer injection	• Groundwater contamination	Moderate	Rare	6 moderate	Moderate	Occasional	9 high
	• Surface water contamination	Moderate	Rare	6 moderate	Moderate	Occasional	9 high

	• Releases to air (local air quality)	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (contribution to global warming)	Minor	Rare	3 low	Minor	Rare	3 low
	• Water resource depletion	Slight	Rare	2 low	Minor	Rare	4 low
	• Land take	Minor	Likely	8 moderate	Minor	highly likely	9 high
	• Noise	Slight	Occasional	4 low	Minor	Occasional (short-term definite)	6 moderate
	• Visual impact	Slight	rare	2 low	Slight	rare	2 low
	• Seismic (induced seismicity)	Slight	Rare	2 low	Slight	Rare	2 low
	• Traffic	Slight	Occasional	4 low	Minor	Occasional	6 moderate
11.10 Well stimulation (low volume hydraulic fracturing) – fracturing to release gas and/or oil.	• Groundwater contamination	Moderate	Rare	6 moderate	Moderate	Occasional	9 high
	• Surface water contamination	Minor	Rare	4 low	Minor	Occasional	6 moderate
	• Releases to air (local air quality)	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (contribution to global warming)	Minor	Rare	3 low	Minor	Rare	3 low
	• Water resource depletion	Slight	Rare	2 low	Minor	Rare	4 low
	• Land take	Minor	Occasional	6 moderate	Minor	Likely	8 moderate

	• Noise	Slight	Occasional	4 low	Minor	Occasional (short-term definite)	6 moderate
	• Visual impact	Slight	Rare	2 Low	Slight	Rare	2 Low
	• Seismic (induced seismicity)	Slight	Rare	2 Low	Slight	Rare	2 Low
	• Traffic	Minor	Rare	4 low	Minor	Occasional	6 moderate

The list of processes and technologies assessed to have possible impact in stage 4 include:

8.1 Implementation of development plan;

9.1 Well commissioning;

10.1 Development drilling;

11.1 Crude oil and gas processing - Operation of plant and process equipment and maintenance activities;

11.2 Well workover – Conducted during monitoring and maintenance of completed wells;

11.3 Site operations – accidental spillages of fluids associated with operations on the platform;

11.4 Process treatment systems - Produced water collection and management;

11.5 Utility systems - Wastewater and sewage collection and treatment;

11.6 Waste Handling - Waste handling, storage, collection and transport;

11.7 Hydrocarbon offtakes - product export, onshore pipelines / road tankers within the production process boundary;

11.8 Water flooding – water injection to sweep field and boost production;

11.9 Enhanced recovery (substance injection) – steam / miscible gas / polymer injection; and

11.10 Well stimulation (low volume hydraulic fracturing) – fracturing to release tight gas and/or oil.

Subsequent sections discuss and outline environmental hazards and impacts for the identified list of processes and technologies in further detail.

5.4.2 Implementation of development plan

5.4.2.1 Overview

Impacts from implementation of the development plan would be similar to those outlined in section 5.1 sub-stage 4 of site preparation but with a larger scope. Environmental impacts that can arise include the following (UNEP/O&G, 1997):

- Long term loss of habitat and land use;

- Permanent facilities requiring increased footprint (landtake);
- Long-term effects of vegetation clearance, erosion and changes in surface hydrology;
- Larger scale, construction activities, noise, vibrations and emissions related to earth works (e.g. possible pipelines construction); and
- Aesthetic and visual intrusion.

5.4.2.2 Measures

Current practices in the oil and gas industry are assumed to have the following risk management measures in place (UNEP/O&G, 1997 and RPS, 2015):

- Required licences that may include (depending on the member state in which the activities occur) an obligation to apply environmental risk management measures in order to conduct oil or gas surveys, exploration and/or production[42];
- Environmental impact assessment[43] carried out to:
    - Establish baseline environmental aspect conditions (e.g. air quality, noise, groundwater, surface water, ecology, landscape);
    - Review of the potential impact on environmental aspects and determination of the required risk management measures to prevent/minimise impacts (e.g. avoiding work that may disturb the breeding and migratory seasons for birds; measures to avoid disturbance to protected species and minimise the amount of areas cleared of vegetation; required materials and wastes storage); and
    - Establish monitoring measures for environmental aspects during operations such as for air emissions, noise abatement, groundwater and surface water monitoring, etc. Refer to Section 2.4.1.2 (licensing) for more detail.
- Site designed to avoid and contain spillages and leakages (IPIECA, 2013) such as: impervious site liner under pad with puncture proof underlay, double-skinned storage tanks, bunded tanks, tank level alarms, collection and control of surface run-off, water aquifer erosion protection and sediment interception;
- Oil-water separators in drainage and ensure access to spill kits (Amec Foster Wheeler, 2015b);
- Waste management plan for construction and operation in place;
- Spill management procedure in place;
- Traffic impact assessment taking account of noise, air emissions and other relevant impacts carried out and a transport management plan established;
- Installation of required emissions control devices on drilling and associated equipment. Engine and equipment use minimised to mitigate emissions to air;
- Fuel efficient generators and vehicles used, and regular maintenance of the vehicles and machines (Apache, 2008);
- Effective site security to ensure that the site is protected to prevent vandalism that may lead to pollution from damaged equipment/infrastructure;

[42] As set out under the EU's Prospection, Exploration and Production of Hydrocarbon Directive.

[43] An EIA is only mandatory if the development is expected to produce more than 500t oil or 500,000m^3 gas per day ((Directive 2011/92/EU as amended by 2014/52/EU). For projects below this threshold, surface industrial installations for the extraction of petroleum and gas, and deep drilling operations, the competent authority screens these projects to determine whether they are likely to have a significant adverse effect on the environment. In the event that the competent authority does not deem it necessary to conduct an EIA in order to grant the permit, then associated risk management measures may not be applied. However, this should be only for projects where environmental risk has been deemed to be low enough for these measures not be required.

- Good construction practices for preventing dust, leaks and spills (i.e. good on-site housekeeping practices such as keeping working areas tidy and clean, regularly removing waste materials and storing items safely);
- Minimising land take and use of existing routes and already disturbed areas during the creation of access routes;
- In construction areas, appropriate cover of dusty construction materials. Dry areas watered to prevent dust emissions from moving vehicles or machinery (Amec Foster Wheeler, 2015b);
- Consideration of decommissioning and restoration in site selection and preparation (UNEP/O&G, 1997); and
- Sites previously chosen at the exploration and development planning stage to encourage natural rehabilitation by indigenous flora, avoiding the removal of vegetation and topsoil and the preservation of topsoil and seed source.

5.4.2.3 Issues

The risk levels for development plan are presented in Table 5.17.

Table 5.17: Risk and impacts of Implementation of development plan

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Water contamination from surface runoff or stormwater runoff from contaminated soil. Soil contamination may occur from leaching mud pits, chemical spillages and leakages from e.g. sewage, camp grey water etc. (UNEP/O&G, 1997)	4 low
Releases to air (local air quality)	Dust emissions from use of dirt tracks. Exhaust emissions from vehicles and generators. (Halcrow, 2004)	4 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate
Land take	Further impact similar to those as set out for the site preparation sub-stage above. Depending on the scale of the development plan, increased number of facilities and more permanent equipment would mean more land would be further converted for industrial use.	12 High
Biodiversity impacts	Refer to site preparation sub-stage. More vegetation cleared; possible erosion and changes in surface hydrology; emissions, vibration and noise from earth moving equipment leading to potential disturbance of local population and wildlife. Potential long-term impacts from access construction. (UNEP/O&G, 1997) Low level noise from camp activities; disturbance to local environment. Short term, transient. (IOGP, 2012)	2 low
Visual impact	Refer to site preparation sub-stage. Further expansion of the site will require construction and/or improved access roads and would result in an increased industrial landscape (Tribal Energy, 2015).	4 low
Noise	Increased duration of construction usage and operation resulting in longer term impact of noise from vehicles and equipment. (UNEP/O&G, 1997)	4 low

Main Environmental Aspects	Impacts	Risk Level
Traffic	Refer to site preparation sub-stage. Further expansion of the site will require construction and/or improved access roads and would result in an increase in traffic. Overweight and oversized loads could cause temporary disruptions and could require extensive modifications to roads or bridges (e.g. widening roads or fortifying bridges). Increased traffic would also result in a potential for increased accidents within the project area. Conflicts between industrial traffic and other traffic are likely to occur, especially on weekends and holidays. (UNEP/O&G, 1997)	4 low

Activities at this stage are on a greater scale compared to those discussed in section 5.1 for sub-stage 4 of site preparation. The overall environmental risk once the development plan is implemented with risk management measures in place is generally considered low with the exception of land take. The impact for land take is significant, depending on the scale of operations. The land previously employed for the exploration phase is now used for production phase and would potentially be subjected to a longer term use (20-30 years for a typical conventional well, depending on market conditions). The impact is attributed to additional infrastructure and systems needed to put in place to extract oil or gas.

5.4.3 Hook up and commissioning

5.4.3.1 Overview

To commence producing proper, wells will need to connect or be "hooked up" appropriately to production, collection, storage or/and treatment systems and then commissioned through introducing testing fluid and then hydrocarbon into the system. Significant environmental impacts are not expected from well "hook-up". Pre-commissioning, which involves chemical testing (e.g. hydrostatic test) and commission (e.g. pressure testing, control testing, etc.), will have the greatest potential for impacts.

5.4.3.2 Measures

Current practices in the oil and gas industry are assumed to have similar measures as stipulated in section 5.4 Stage 3 Development and production, sub-stage 8.1 Implementation of development plan.

Further measures are as follows (Lamberson, 2002):

- Deployment of techniques to maintain well safety[44];
- Implement erosion protection, runoff control and sediment interception for controlled discharge of testing fluid; and
- Pipeline cleaning with cleaning pigs with wire brushes before conducting hydrostatic testing to remove construction debris.

5.4.3.3 Issues

The risk levels for hook up and well commissioning are presented in Table 5.18.

[44] Such as blowout preventers, pressure & temperature monitoring and shutdown systems, fire and gas detection and continuous monitoring for leaks and release of gas and liquids, isolate underground source of drinking water prior to drilling, ensure micro-annulus is not formed, casing centralizers to centre casing in hole, select corrosive resistant alloys and high strength steel, fish back casing, maintain appropriate bending radius, triple casing, isolation of the well from aquifers.

Table 5.18: Risk and impacts of hook up and well commissioning

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Minimal impact expected during hook-up, pre-commissioning and commissioning. However if the well were constructed inadequately or poorly, there is significant potential to contaminate groundwater by hazardous chemicals (e.g. hydrostatic testing, chemical dosing, etc.). (Amec Foster Wheeler, 2015b)	6 Moderate
Surface water contamination	Pre-commissioning stage will have the most significant potential for impacts as this activity involves hydrostatic testing water availability, chemical dosing and water disposal. If handled inappropriately or in case of spillage or accident, this can result in surface runoff of harmful chemicals released into surface water bodies. Erosion and sedimentation at discharge point of testing liquids. (Lamberson, 2002)	4 low
Releases to air (local air quality)	Flaring as a safety measure during start up, maintenance or emergency during normal processing operations. Emissions can include carbon dioxide, carbon monoxide, methane, VOCs, NOx, SOx, hydrogen sulphide (UNEP/O&G, 1997).	3 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate
Water resource depletion	Water is required for the hydrostatic testing of the well during pre-commissioning. The quantity of water needed is expected to be relatively small and only required when undertaking the test. (Amec Foster Wheeler, 2015b).	2 low
Biodiversity impacts	Toxic chemical spill from hydrostatic testing can lead to permanent loss of plant and habitat. (Amec Foster Wheeler, 2015b)	2 low
Noise	Noise from machinery, power plant and equipment. (UNEP/O&G, 1997)	4 low

The risk levels for hook up and commissioning activities are judged as generally low apart from risks to groundwater and surface water which are thought to be generally moderate due to the potential for persistent contamination leading to gradual seepage and leakage into groundwater (if the event occurred). Effective treatment of contaminated groundwater may be challenging.

5.4.4 Development drilling

5.4.4.1 Overview

The scale of development drilling will be determined by the agreed development field plan[45]. Further well drilling or enhancements for oil or gas production may be required on a large field. Development drilling requires a derrick, drilling mud handling equipment, power generators, cementing equipment and tanks for fuel and water, etc. The environmental hazards and impacts are similar to those stipulated under drilling; however there may be cumulative impacts due to the increased scale of operations.

[45] For details on well drilling, completion and commissioning refer to previous sections.

5.4.4.2 Measures

Current practices in the oil and gas industry are assumed to have similar measures as stipulated in sub-stage 8.1 (Implementation of development plan). Further assumed measures are as follows:

- Reinjection of gas decreases the volume of gas which may have been flared. This practice will increase well yield and decrease related air greenhouse gas pollution (Apache, 2008);
- Implementation of local groundwater protection policies and management plans (through permit conditions) (USGS, 2014);
- For drilling through groundwater aquifers, appropriate drilling fluid is used (i.e. water based mud); and
- Good housekeeping practices (including keeping working areas tidy and clean, regularly removing waste materials and storing items safely) on the rig site to help minimise risk of discharge on land and other impacts such as leaks, accidental spills, etc. (Haliburton, 2012).

5.4.4.3 Issues

The risk levels for development drilling are presented in Table 5.19.

Table 5.19: Risk and impacts of development drilling

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Refer to drilling activities in exploration for related impacts. Risks to groundwater are mainly those posed by inadequate design or poor construction of well completion leading to potential aquifer contamination. Of most concern are the naturally occurring substances such as heavy metals, natural gas, dosing chemicals used to maintain the well, etc. from production processes. Production may open an exposure route for surface contaminants to leak into groundwater if the well is not correctly constructed.	6 Moderate
Surface water contamination	Refer to drilling activities in exploration for related impacts.	4 low
Releases to air (local air quality)	The main sources of carbon dioxide emissions are from production operations. Other releases to air include methane arising from process vents and potentially from leaks, flaring and combustion. (UNEP/O&G, 1997). Principal pollutants from combustion processes include nitrogen oxides, sulphur oxides, carbon monoxide and particulates. Additional pollutants from flaring and leakages can include: hydrogen sulphide (H2S); volatile organic compounds (e.g. methane and ethane), benzene, ethyl benzene, toluene and xylenes (BTEX), glycols and polycyclic aromatic hydrocarbons. (Shell, 2011)	3 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 moderate
Water resource depletion	Refer to drilling activities in exploration for related impacts	4 low
Land take	Refer to drilling activities in exploration for related impacts	10 high

Main Environmental Aspects	Impacts	Risk Level
Biodiversity impacts	Contaminating substances associated with petroleum products may leak and contaminate soil. Impacts, if occurring, can be persistent but are generally in the immediate vicinity of the drilling and production activity. Contamination can be variable depending on methods and materials used and the occurrence of spills. The levels of contaminating agents may not represent immediate environmental threats, but there may be long-term cumulative effects of soil alteration and toxicants on organisms. (Carlsal, 1995)	4 low
Noise	Refer to drilling activities in exploration. Scale of impacts (geographical) is expected to be larger than that of exploration phase.	4 low
Visual impact	Additional components that would adversely affect the visual character of the landscape are overland pipelines leading off the site, pumping units, compressor stations, equipment storage areas, and, if required, nearby worker housing units and airstrips. (Tribal Energy, 2015)	15 very high
Traffic	Refer to drilling activities in exploration	4 low

The stage is similar to sub-stage 8.1 implementation of development plan where environmental risks are considered low with the exception of land take. The risk levels for land take and visual impacts are considered generally high due to increased land area required for further drilling development and changes to more widespread 'industrial' land use. As indicated in previous processes and technologies, due to the difficulty of treating contaminated groundwater, the risk to groundwater would be moderate.

5.4.5 Crude oil & gas processing

5.4.5.1 Overview

On arriving at the surface, the hydrocarbon may include a mixture of oil, dissolved gas and produced water or mainly gas and produced water in gas fields, which are separated at the production facility prior to being sent offsite for refining. Long-term occupation of site and permanent production facilities leads to long-term and increased potential to impacts. Increased impacts include (UNEP/O&G, 1997):

- Demand on local infrastructure water supply, sewage, solid waste disposal;
- Discharges and emissions from facilities managing wastewater, produced water, sewage and surface runoff;
- Power and process plant emissions such as waste gases, flaring emissions, noise, vibration and light; and
- Increased risk of soil and water contamination from spillage and leakage.

5.4.5.2 Measures

Current practices in this sub-stage are assumed to be similar measures as those stipulated in sub-stage 8.1 (Implementation of development plan). Further assumed measures are:

- Implementation of remedial measures if well failure occurs;

- Deployment of key elements to maintain well safety[46]; and
- Implementation of process control systems (i.e. process shutdown), ICT (communications technology) infrastructure (i.e. production, maintenance, communications, sensing and surveillance) and safety instrumented systems (i.e. emergency shut down and fires and gas emissions to air) (Johnsen, 2008).

5.4.5.3 Issues

The risk levels for crude oil and gas processing are presented in Table 5.20.

Table 5.20: Risk and impacts of crude oil & gas processing

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Long term contamination of the surface by accidental spills, etc. may contaminate soil in the immediate vicinity leading to contamination of groundwater bodies.	6 Moderate
Surface water contamination	Surface runoff of any spillages and leakages not cleaned up or detected during crude oil and gas processing.	4 low
Releases to air (local air quality)	Flaring of gas. Emissions from machinery, equipment, power plant, etc.	6 Moderate
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change. For oil and gas processing the related emissions are potentially greater than in other processes covered under the life-cycle, but are expected to be periodic	9 high
Noise	Noise from treatment machinery, power plant and equipment.	3 low
Traffic	Impact is expected to be minimal from vehicles.	4 low

Frequent flaring of gas or VOC releases would have an impact on local air. Contaminated groundwater is expected to generally have a moderate risk level due to the potential difficulty of treating contaminated groundwater (if this occurred).

5.4.6 Site operations

5.4.6.1 Overview

All site operations associated with oil and gas exploration and production carry a risk of accidental spillages of chemicals, hydrocarbons, drilling mud or cement. Expected environmental hazards for site operations are derived from spillages of liquid contaminating groundwater or surface water, air emissions from gaseous spills degrading local air quality and contributing to climate change and impacts to biodiversity from toxic spills to the surrounding environment. The likelihood of accidental spillages may increase when the site is situated in extreme climates, has more severe process conditions such as higher temperatures and pressures, larger and more complex facilities, inhospitable regimes and greater financial and resource challenges as competition increases. This is because there is greater stress put on the

[46] Such as blowout preventers, pressure & temperature monitoring and shutdown systems, fire and gas detection and continuous monitoring for leaks and release of gas and liquids, isolate underground source of drinking water prior to drilling, ensure micro-annulus is not formed, casing centralizers to centre casing in hole, select corrosive resistant alloys and high strength steel, fish back casing, maintain appropriate bending radius, triple casing, isolation of the well from aquifers.

oil and gas processes, containment equipment and lower margins for operator error during production.

A tiered approach is often used to rank offshore accidental events detailed by the IPIECA (2007) (see section 6.4.7.1). While the same approach is encouraged for onshore operations, the uptake and applicability of this ranking is currently unknown. Due to limited information, the three tiered approach was not used for this risk assessment for onshore operations. A different ranking was used to assess the onshore risks. Accidental events were divided into those that may have catastrophic impacts or require major long term monitoring and clean-up. Events that can be controlled quickly and do not require third party assistance are considered minor events.

The environmental aspects likely to be affected by this process covers:

- Groundwater contamination – spilt liquids penetrating groundwater;
- Surface water contamination – spilt liquids reaching surface water;
- Releases to air – of hydrocarbons or chemicals; and
- Impacts on biodiversity – released or spilt toxic substances affecting the surrounding environment.

5.4.6.2 Measures for major events

Examples of measures in place to control against major accidental spills include:

- Primary well control;
- Use of blow-out preventers;
- Valve assembly systems to manage flow of material and prevent loss to the surrounding environment;
- Well pressure monitoring (well management);
- Emergency plans and training including spill clean-up procedures and if necessary specialist spill response operators; and
- Spill clean-up resources.

5.4.6.3 Issues

The risk levels for process treatment systems are presented in Table 5.21.

Table 5.21: Risk and impacts of major accidental event from oil & gas processing

Main Environmental Aspects	**Impacts**	**Risk Level**
Groundwater contamination	If contamination of the ground surface occurs through spillages or accidents, etc., this may lead to contamination of groundwater bodies. (UNEP/O&G, 1997) Well blowout due to failure of blowout preventers or well bore ruptures can release spills of oil and drilling fluid and create plumes of groundwater pollution (Golder 2014). Comparable data for blowout risks are currently not available. However it has been recommended by the International Association of Oil and Gas Producers to use Offshore risk likelihood data (IOGP 2010b).	10 high

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Surface runoff and storm water runoff contaminated by the spill can reach rivers, resulting in the pollution of a water source that serves both humans, flora and fauna. Well blowout due to failure of blowout preventers or well bore ruptures can release spills of oil and drilling fluid and create plumes of groundwater pollution (Golder 2014). Comparable data for blowout risks are currently not available. However it has been recommended by the International Association of Oil and Gas Producers to use Offshore risk likelihood data (IOGP 2010b).	10 high
Releases to air (local air quality)	Emissions of large quantities of fugitive hydrocarbon gas or volatile chemicals can result in the degradation of local air quality.	8 moderate
Impacts to biodiversity	Releases of large quantities of toxic substances can potentially result in adverse effects on surrounding environments such as local habitats and flora and fauna.	10 high

Out of six major onshore oil and gas accidents that have occurred globally from 2003 to 2010, only one of the events (a sour gas blowout) was considered reported from oil and gas upstream processes (RSP, 2011). There is very little information or evidence of any major accidental releases or spillages for Europe.

According to the risk assessment data directory (OGP, 2010), while statistical data are available on events such as blowouts for the offshore sector, comparable data for blow out incidents were not found and it was recommended that frequencies for offshore also be applied to onshore. While based on a study for Alberta, the frequency for onshore drilling blowouts was reported to be 40% of the corresponding value for offshore drilling blowouts and well releases (the frequency for blowouts was indicated to be in the region of 4.4 x10^{-4} blowouts per well drilled), since the wells found in Alberta are considered to be sour, with more precautions taken to minimise likelihood of releases, the frequency may be expected to be higher. Following the recommendation by OGP 2010 report to assess using offshore data, risk for major event is considered to be rare.

5.4.6.4 Measures for minor events

Examples of measures in place to control against minor accidental spills include:

- Use of blow-out preventer;
- Valve assembly systems to manage flow of material and prevent loss to surrounding environment;
- Well pressure monitoring (well management);
- Emergency plans and training including spill clean-up procedures and if necessary specialist spill response operators; and
- Spill clean-up resources.

5.4.6.5 Issues

The risk levels for process treatment systems are presented in Table 5.22.

Table 5.22: Risk and impacts of minor accidental events from oil & gas processing

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	If contamination of the ground surface occurs through spillages or accidents (e.g. loss of containment of fuel storage; loss of containment of chemicals; smaller hydrocarbon releases) this may lead to contamination of groundwater bodies (UNEP/O&G, 1997).	8 Moderate
Surface water contamination	Surface runoff and storm water runoff contaminated by a minor spill (e.g. loss of containment of fuel storage; loss of containment of chemicals; smaller hydrocarbon releases) can reach rivers, resulting in the pollution of a water source that serves both humans, flora and fauna.	8 moderate
Releases to air (local air quality)	Emissions of large quantities of fugitive hydrocarbon gas or volatile chemicals can result in the degradation of local air quality.	4 low
Impacts to biodiversity	Releases of toxic substances can potentially result in adverse effects on surrounding environments such as local habitats and flora and fauna.	8 moderate

5.4.7 Well workover

5.4.7.1 Overview

Well workovers or interventions, are performed by inserting tools into wellbores to conduct maintenance, testing or remedial actions. The main environmental impacts would potentially be to surface waters where any chemical spillages or leakages may contaminate surface water bodies via surface runoff.

5.4.7.2 Measures

Current practices in this sub-stage are assumed to be similar to those stipulated in sub-stage 8.1 Implementation of development plan. Further measures are as follows:

- Implement management of wellbore maintenance in accordance with waste management procedures, in particular, deploy sediment interception, surface water protection and runoff control.

5.4.7.3 Issues

The surface water impact for well workover is presented in Table 5.23.

Table 5.23: Risk and impacts of well workover

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Surface runoff and stormwater runoff contaminated.	4 low

5.4.8 Process treatment systems (produced water)

5.4.8.1 Overview

The vast majority of oil and gas wells produce a proportion of water alongside hydrocarbons. This proportion tends to increase over the lifetime of the well.

Occasionally a well may produce little or no water for the first few months of production, or even the whole production lifetime. Similar to drilling for exploratory wells, produced water may be produced in development wells and during the production process of the development well. Expected environmental hazards for process treatment systems would be to groundwater, surface water, releases to air and noise.

5.4.8.2 Measures

Current practices for risk management measures for process treatment systems are expected to be assessed and stipulated as part of those listed in section 5.4 (Stage 3 Development and production, sub-stage 8.1 Implementation of development plan).

Further measures are as follows (UNEP/O&G, 1997):

- Reusing treated producing water to suppress dust emissions for access road and sites (this is not widely practised in the EU)[47];
- Injection of produced water with minimal pre-treatment (only to increase injectivity) into the original formation or another strata that will contain the water without migration[48];
- Treatment of produced water to meet onshore discharge or use standards; and
- Reuse of produced water in oil and gas operations such as for drilling, stimulation and workover operations.

5.4.8.3 Issues

The risk levels for process treatment systems are presented in Table 5.24.

Table 5.24: Risk and impacts of process treatment systems

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	If contamination of the ground surface occurs through spillages or accidents, etc., this may lead to contamination of groundwater bodies. (UNEP/O&G, 1997)	6 Moderate
Surface water contamination	Surface runoff and storm water runoff contaminated by produced water. Produced water (from the target formation) is recovered during well development. Generation can be an issue during the development phase, although it usually becomes a greater waste management concern over the long-term operation of an oil or gas field because water production typically increases with the age of the production well. Typical watercuts (proportion of produced water to oil) range from 25% or lower at the start of production (1 barrel of water produced per 3 barrels of oil) to 75% or higher later in production (3 barrels of water produced per 1 barrel of oil) (IFC, 2007).	4 low

[47] Some studies and articles have reported that in the US, spreading of produced water is widely practiced. It was also indicated that the produced water was often spread untreated. The scale of which spreading on road is conducted in EU is currently unknown. However measures practiced here should ensure that the produced water is treated to make sure it is suitable for road spreading use. http://europe.newsweek.com/oil-and-gas-wastewater-used-de-ice-roads-new-york-and-pennsylvania-little-310684

[48] There are differences in opinion amongst EU member states about the re-injection of wastewaters from onshore O&G installations, as highlighted in a report for the Commission (Milieu, 2013); this report was focused on hydraulic fracturing. The extent to which such reinjection occurs in practice across the EU member states is not known.

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	Dust emissions from use of dirt tracks. Exhaust emissions from vehicles and generators. (UNEP/O&G, 1997)	2 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	2 low
Noise	Noise from treatment machinery and equipment. Engines and vehicles transporting and running the waste facility plant. (UNEP/O&G, 1997)	4 low

With proper risk management measures in place ensuring proper containment or management of produced water, the environmental risk is considered to be low in general for surface water, releases to air and noise impacts. Groundwater contamination is assessed as generally moderate as any resulting impact (contamination) is difficult to remediate.

5.4.9 Utility systems

5.4.9.1 Overview

Utility systems are required as part of production phase for management of sludge from collection tanks, sewage, grey water and wastewaters will have similar impacts to process treatment facilities (as discussed above).

5.4.9.2 Measures

Assumed risk management measures for utilities systems are the same as those in sub-stage 8.1 (Implementation of development plan).

5.4.9.3 Issues

The risk levels for utility systems are presented in Table 5.25.

Table 5.25: Risk and impacts of utility systems

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	If contamination of the ground surface occurs through spillages or accidents, etc., this may lead to contamination of groundwater bodies. (UNEP/O&G, 1997)	6 Moderate
Surface water contamination	Surface runoff and stormwater runoff contaminated by sewage	4 low
Releases to air (local air quality)	VOCs from oily sludge and drill cuttings. Emissions from plant machinery, power plant, engines and vehicles transporting the waste. (UNEP/O&G, 1997)	2 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change. However the overall effects are likely to be slight.	2 low
Noise	Noise from machinery and equipment (UNEP/O&G, 1997) and engines and vehicles transporting and powering facilities.	4 low

Main Environmental Aspects	Impacts	Risk Level
Traffic	Impact may be minimal; however some traffic would be generated from transportation of wastewater for treatment.	4 low

With risk management measures in place ensuring containment or management of the utility systems, the environmental risk is considered to be low in general for surface water, releases to air and noise impacts. Groundwater contamination risk is assessed as generally moderate as any resulting impact (contamination) is difficult to remediate. Waste from the utility system will require further treatment and disposal offsite and require transport.

5.4.10 Waste handling

5.4.10.1 Overview

Waste handling on site, required as part of the production phase for management of waste arising from production activities, is expected to have similar impacts to process treatment facilities and utilities systems (as discussed above).

5.4.10.2 Measures

Practices for risk management measures for process treatment systems are expected to be assessed and stipulated as part of those listed in sub-stage 8.1 Implementation of development plan". Further assumed measures are as follow (UNEP/O&G, 1997):

- Use of chemicals with lower environmental impact for drilling operations (hence leading to a reduced contamination of waste);
- Re-use, recycling and minimisation of waste; and
- Appropriate and effective pre-treatment facilities (e.g. thermal desorption and detoxification).

5.4.10.3 Issues

The risk levels for waste handling are presented in Table 5.26.

Table 5.26: Risk and impacts of waste handling

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	If contamination of the ground surface occurs through spillages or accidents, etc., this may lead to contamination of groundwater bodies. (UNEP/O&G, 1997)	6 Moderate
Surface water contamination	Surface runoff and stormwater runoff that may be contaminated by spills and unplanned releases of wastes, oily mud, etc.	4 low
Releases to air (local air quality)	VOCs from oily sludge, drill cuttings. Emissions from plant machinery, power plant, engines and vehicles transporting the waste. (UNEP/O&G, 1997)	3 low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change. However the overall effects are likely to be slight.	3 low

Main Environmental Aspects	Impacts	Risk Level
Noise	Noise from machinery and equipment (UNEP/O&G, 1997) and engines and vehicles transporting and powering facilities.	4 low
Traffic	Impact may be expected from traffic associated with transportation of waste for treatment and disposal. The quantity of waste transported varies greatly depending on site-specific factors.	4 low

With risk management measures in place ensuring containment or management of waste, environmental risks are considered to be generally low. Groundwater contamination risk is assessed as moderate as any resulting impact (contamination) is difficult to remediate.

Wastes require further treatment and disposal and are therefore transported off site.

5.4.11 **Hydrocarbon offtakes**

5.4.11.1 Overview

Once the required onsite crude oil or gas processing is complete, the product is transported off-site to refineries by tanker or pipeline (in the case of oil) or for distribution to the gas network. Associated environmental hazards arise from accidental leakage or spillage for oil, associated with oil transfer activities, and from potential leakage (e.g. from valves) for gas, resulting in releases to air. Release to air and noise from vehicles are also relevant.

5.4.11.2 Measures

Practices for risk management for process treatment systems are expected to be assessed and stipulated as part of those listed in sub-stage 8.1 (Implementation of development plan).

5.4.11.3 Issues

The risk levels for hydrocarbon offtakes are presented in Table 4.27.

Table 5.27: Risk and impacts of hydrocarbon offtakes

Main Environmental Aspects	Impacts	Risk Level
Surface water contamination	Surface runoff and stormwater runoff that may be contaminated by waste chemicals, oily mud, etc. due to accidental spills or leakage.	4 low
Releases to air (local air quality)	Emissions from plant machinery, valve leakage, power plant, engines and vehicles transporting the waste. (UNEP/O&G, 1997)	2low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	5 Moderate
Noise	Noise from machinery and equipment (UNEP/O&G, 1997) and engines and vehicles transporting and powering facilities.	4 low

Main Environmental Aspects	Impacts	Risk Level
Traffic	Impact may be expected from traffic where transportation of hydrocarbon offtakes off-site takes place by tanker.	4 low

Risks are considered to be generally relatively low for the outlined environmental aspects.

5.4.12 Water flooding

5.4.12.1 Overview

This involves injection of water to sweep the hydrocarbon reserve and boost production from the primary well, by displacing trapped oil. Large volumes of water are required, which must be stored, treated, pressurised and injected. This may have the potential to put a strain on local water resources, as injected water is removed from the water cycle for prolonged periods of time. The quantity of water used varies greatly depending on site-specific factors such as the size of the reservoir and the water resource available. In addition, water injection is often an ongoing process, which is repeated until the water cut of the produced oil is so high (90-99%) that the well is no longer economically viable. For these reasons, no illustrative ranges of volumes of water used in water flooding could be found.

5.4.12.2 Measures

Examples of measures applied include:

- BAT technology for low sulphur fuels in vehicles and pressurising equipment;
- Maintenance programmes for all equipment;
- Emergency plans;
- Noise abatement measures; and
- Planning of water resource use[49].

5.4.12.3 Issues

The risk levels for water flooding are presented in Table 5.28.

[49] This includes spatial planning to ensure that groundwater and surface water are taken from areas where the risks of depletion are low. It also involves temporal planning to ensure that surface waters and groundwater are not extracted or diverted during times where the risks of water stressed are increase, or for prolonged/continuous periods.

Table 5.28. Risks and impacts of water flooding

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	Emissions of SO_2, NOx and dust from the equipment and vehicles used to clean, pressurise and inject water	4 low
Releases to air (contribution to global warming)	Emissions of CO_2 from the equipment used to pressurise and clean injection water.	3 low
Water resource depletion	Depletion resulting from the high water demand	4 low
Land take	Increased land take resulting from the need to store water /demineralisation equipment in addition to the equipment required for pressurisation, injection and injection wells.	8 moderate
Noise	Noise resulting from equipment used to pressurise and inject the water	4 low
Visual impact	Visual impact due to physical presence of water storage and injection equipment	2 low
Traffic	Increased traffic required to transport equipment and materials for the injection	4 low
Seismicity	Small risk of induced seismicity from the pressures applied during injection (Rubinstein & Mahani, 2015).	2 low

5.4.13 Enhanced recovery (substance injection)

5.4.13.1 Overview

This involves injection of steam, polymers, CO_2 or hydrocarbon gas into the well to boost production rates and overall recovery factor. Space is required for substance storage and equipment for compression and injection.

5.4.13.2 Measures

Examples of measures applied include:

- Use of injection chemicals with lower environmental hazard/risk;
- BAT technology for low sulphur fuels in vehicles and pressurising equipment;
- Bunding, protected skids and totes for fluid storage;
- Maintenance programmes for all equipment;
- Emergency plans; and
- Noise abatement measures.

5.4.13.3 Issues

The risks for substance injection are presented in Table 5.29.

Table 5.29. Risks and impacts of substance injection

Main Environmental Aspects	**Impacts**	**Risk** Level
Groundwater contamination	Chemicals penetrating subsurface groundwater due to the proximity of the wellbore to groundwater.	6 moderate
Surface water contamination	Surface or stormwater runoff may be contaminated with injection chemicals.	6 moderate
Releases to air (local air quality)	Emissions of SO_2, NOx and dust from the equipment and vehicles used to transport, pressurise and injection substances (and/or heat steam).	4 low
Releases to air (contribution to global warming)	Emissions of CO_2 from the equipment used to pressurise and inject substances / heat steam.	3 low
Water resource depletion	Polymers and gases are often injected alongside water, additionally steam is produced using local water resources. This presents a slight risk of depleting local water resources.	2 low
Land take	Increased land take resulting from the need to store large quantities of gas/chemicals above ground, in addition to the equipment required for pressurisation and injection.	8 moderate
Noise	Noise resulting from equipment used to pressurise and inject the substance	4 low
Visual impact	Visual impact due to physical presence of fluid storage and injection equipment	2 low
Traffic	Increased traffic required to transport equipment and materials for the injection.	4 low
Seismicity	Small risk of induced seismicity from the pressures applied during injection (Rubinstein & Mahani, 2015).	2 low

5.4.14 Well stimulation (low volume HF)

5.4.14.1 Overview

Low volumes of water, together with a proppant such as sand and other chemicals including thickening agents and surfactants, are injected into the well to fracture the formation containing the hydrocarbons. Associated environmental hazards arise from the need to supply and store large quantities of liquid and chemicals at the site, in addition to removing the waste or 'flowback'.

5.4.14.2 Measures

Examples of measures applied include:

- Use of fracturing chemicals/additives with lower environmental hazard/risk;
- BAT technology for low sulphur fuels in vehicles and pressurising equipment;
- Bunding, protected skids and totes for fluid storage;
- Maintenance programs for all equipment;
- Emergency plans;
- Noise abatement measures; and
- The use of reduced emissions completions ("green completions").

5.4.14.3 Issues

The risk levels for enhanced recovery using low volume hydraulic fracturing are presented in Table 5.30.

Table 5.30: Impacts and risks of low volume hydraulic fracturing

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Fracturing fluids penetrating subsurface groundwater due to the proximity of the fracturing operation to groundwater reserves.	6 moderate
Surface water contamination	Surface or stormwater runoff may be contaminated with either fracturing fluids or flowback	4 low
Releases to air (local air quality)	Emissions of SO_2, NOx and dust from the equipment and vehicles used to transport, pressurise and injection fracturing fluids, and process flowback.	4 low
Releases to air (contribution to global warming)	Emissions of CO_2 from the equipment used to pressurise and injection fracturing fluids, and process flowback.	3 low
Water resource depletion	Depletion resulting from the high water demand of fracturing operations.	2 low
Land take	Increased land take resulting from the need to store large quantities of fracturing fluids and chemicals and flowback above ground, in addition to the equipment required for pressurisation and injection.	6 moderate
Noise	Noise resulting from equipment used to pressure and inject the fracturing fluid	3 low
Visual impact	Visual impact due to physical presence of fluid storage and injection equipment	2 low
Seismic	Seismicity induced by the force of the subterranean fracturing process.	2 low
Traffic	Increased traffic required to transport equipment and materials for the fracturing operation.	4 low

5.5 Stage 4 Project cessation, well closure and decommissioning

5.5.1 Summary of environmental risks

The processes for project cessation, well closure and decommissioning are as follows:

Sub-stage 12 Decommissioning and rehabilitation planning

a. Project cessation, well closure and decommissioning

Sub-stage 13 Decommissioning of equipment and reclamation

a. Plugging of wells, removal of well pads and waste management

Sub-stage 14 Rehabilitation

a. Site restoration

The summary of risks for stage 5 Well Site abandonment are outlined in Table 5.31 Further details of the risk assessment can be found in Appendix A.

Table 5.31: Summary environmental hazards and risk level for stage 5 well site abandonment

Processes/ technologies	**Environmental Aspects**	**Risk Characterisation** (**with** expected management measures in place)			**Risk Characterisation** (**without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
12. Decommissioning and rehabilitation planning							
Project cessation, well closure and decommissioning	Planning the deployment of decommissioning task - no specific risk identified so not considered further.						
13. Decommissioning of equipment and reclamation							
13.1 Decommissioning - Plugging of wells, removal of well pads and waste management	• Groundwater contamination	Rare	Moderate	6 Moderate	Occasional	Moderate	9 high
	• Surface water contamination	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (local air quality)	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Releases to air (contribution to global warming)	Rare	Minor	4 low	Likely	Minor	8 moderate
	• Land take	Likely	Slight	4 low	Likely	Minor	8 moderate
	• Visual impact	Likely	Slight	4 low	Likely	Minor	8 moderate
	• Biodiversity impacts	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Noise	Likely	Slight	4 low	Likely	Slight	4 low
	• Traffic	Likely	Slight	4 low	Likely	Slight	4 low
14. Rehabilitation							
14.1 Site restoration	• Noise	Occasional	Slight	3 Low	Likely	Slight	4 low
	• Traffic	Occasional	Slight	3 Low	Likely	Slight	4 low
	• Releases to air (local air quality)	Rare	Minor	4 low	Occasional	Minor	6 moderate

	• Releases to air (contribution to global warming)	Rare	Minor	4 low	Likely	Minor	8 moderate

The list of processes and technologies assessed to have possible impact in stage 5 include:

13.1 Decommissioning - plugging of wells, removal of well pads and waste management

14.1 Site restoration

Subsequent sections here discuss and outline each environmental hazard impact for the identified list of processes and technologies in further detail.

5.5.2 Decommissioning - plugging of wells, removal of well pads and waste management

5.5.2.1 Overview

At the end of the well's productive life, actions are taken to plug and seal the well and remove all development infrastructure. Similar to site preparation in exploration or field development for production, increased numbers of vehicles, plant and machinery will be used for dismantling and removal activates. These activities would generate waste and increase the frequency of emissions to air and noise for the duration of the decommissioning activities.

5.5.2.2 Measures

Measures that maybe in place are (UNEP/O&G, 1997):

- Development and implementation of a decommissioning plan (as outlined during exploration and development planning);
- Good deconstruction practices, including design for well abandonment;
- Specific post closure risk assessment, well plugging, inspection and monitoring requirements (e.g. for releases to air, water quality, well integrity, periodicity of inspections, wellhead monitoring every 90 days) see 2.4.1.2 – licensing for monitoring details;
- Specific post closure well inspection, maintenance and monitoring/reporting programme;
- Removal of invasive species grown on the site;
- Slope stabilisation; and
- Re-vegetation to avoid and minimise erosion.

5.5.2.3 Issues

The risk levels for decommissioning are presented in Table 5.32.

Table 5.32: Risk and impacts of plugging of wells, removal of well pads and waste management

Main Environmental Aspects	**Impacts**	**Risk Level**
Groundwater contamination	Risk of migrating dissolved constituents from long term spillages or leakages to aquifers. Volatilisation of VOCs into vadose zone, infiltration of groundwater to basements, wetlands and surface water or into soils. (IPIECA, 2014) Improper controls, accidents and spillages can result in soil and water contamination. (UNEP/O&G, 1997)	6 Moderate
Surface water contamination	Improper controls can results in soil and water contamination and erosion and changes in surface hydrology from decommissioning activities. (UNEP/O&G, 1997) Potential leaks leading to staining, smells, sheens on water surfaces. (IPIECA, 2014)	4 Low
Release to air (local air quality)	Risk of odours from accidental leaks of waste chemicals and hydrocarbons from decommissioning the well and associated facilities or from vehicles and deconstructed areas. Migration of contaminated soil vapours into air (E&P Forum, 1996) Potential methane seepage to occur in the long term if seals or liners break down. (AEA, 2012)	4 Low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	4 Low
Land take	It may not be possible to return the entire site to beneficial use following abandonment (e.g. due to concerns regarding public safety). Over a wider area this could result in loss of land and/or fragmentation of land area. (AEA, 2012)	4 Low
Visual impact	Not all of wellhead equipment may be removed from site. (AEA, 2012)	4 Low
Biodiversity impacts	Soil contamination by VOCs. Wetlands, wildlife, livestock, fish, amphibians, birds, agricultural areas, surface and drinking water and parks or recreational facilities can all be affected (IPIECA, 2014). Soil is a significant concern; texture, consistency, pH, salinity, organic matter, nutrients and TPH (total petroleum hydrocarbon) can all impact the biodiversity of the site and should be monitored (OGP, 2007) Improper controls can results in soil and water contamination; erosion and changes in surface hydrology; wildlife disturbance; loss of habitat; impacts to biodiversity; human and cultural disturbances; changes in land and resource use. (UNEP/O&G, 1997)	4 Low
Noise	Noise from decommissioning machinery and equipment, vehicle engines and power plant. (UNEP/O&G, 1997). Impact would be short term and transient.	4 Low
Traffic	Vehicle activity will increase as equipment and infrastructure is removed. (Marathon, Undated)	4 Low

Similar to activities from exploration and production, controls applied in the same way during decommissioning and aftercare will mitigate many of the risks. Risk levels are therefore thought to be low in general with the exception of those for groundwater. Any spillages and leakages onto the ground could result in long-term impact. Land take and visual impact are considered as part of environmental hazards due to the equipment potentially remaining on site permanently. Nevertheless impact is assessed as generally being relatively low, in view of the small scale of the equipment (AEA, 2012).

5.5.3 Site restoration

5.5.3.1 Overview

With the removal of the infrastructure, the cleared area should be restored. Processes required to restore sites include stabilising areas and slopes, breaking-up compacted surfaces, re-vegetation, replacement of topsoil, and seeding new vegetation. Noise and traffic issues from transporting the required plant and equipment are the main environmental aspects for this activity.

5.5.3.2 Measures

Typical measures are those referred to in the description of process 13.1 (Decommissioning - plugging of wells, removal of well pads and waste management). Further measures also assumed are as follows:

- Implementation of site restoration plan;
- Environmental monitoring of the site as stipulated in monitoring plans such as EIA, operation plan, Environmental Statement, etc. Please refer to 2.4.1.2 – licensing for more detail;
- Restoration of indigenous plant species; and
- Restoration of drainage patterns.

5.5.3.3 Issues

The risk levels for site restoration are presented in Table 5.33.

Table 5.33: Risk and impacts of site restoration

Main Environmental Aspects	Impacts	Risk Level
Noise	Vehicles to transport equipment and machinery for site restoration activities.	3 Low
Traffic	Vehicles to transport equipment and machinery for site restoration activities.	3 Low
Release to air (local air quality)	Potential local air quality effects from vehicle emissions and increased traffic to and from site. However this is expected to be of lower volumes than in other parts of the life-cycle.	4 Low
Releases to air (contribution to global warming)	Along with fuel related emissions that have the potential to affect local air quality, the emissions of greenhouse gases will also have a contribution towards climate change.	4 Low

Noise and traffic impact are expected to be generally relatively low in risk level. This is because the nature of the site restoration activity is expected to be short and transient and on a much lower scale than those observed during site exploration and production.

5.6 Stage 5 Project post closure and abandonment

5.6.1 Summary of environmental risks

The process of project closure and abandonment is described below.

Sub-stage 15 Post closure and abandonment

a. Monitoring of the site post-closure, which may be outlined in monitoring plans such as in the Environmental impact assessment, environmental statement, etc. Please refer to 2.4.1.2 – licensing for more information; and

b. Relinquishing licences.

Owners of wells are responsible for proper closure and abandonment. Wells may be sold numerous times before they are no longer economically viable. Therefore the owners at the time of abandonment may lack the resources to complete the closure properly. In this case the company may declare bankruptcy, creating a liability issue for the proper abandonment of the 'orphan well'. Alternatively the well may be closed improperly to save costs, which increases risks of long-term integrity failure. Orphan wells impose significant costs on competent authorities, who must fund proper abandonments and even clean-ups if the owner cannot pay, It is estimated that there are between 50 – 100 orphan wells in the UK alone (IEA, 2014). The proper closure and abandonment of orphan wells tends to be completed by the local authority, who recover the costs through taxes from O&G operators. A recent study by Ho et al. (2016) has concluded that in the US, states tends to bear the financial burden of orphan wells, because the bonds amounts required of operators are generally too low to cover decommissioning costs. It is explained that in the US in some cases, due to a lack of monitoring capacity, a well that has been inactive for an extended period of time and is noncompliant with environmental standards may be allowed to remain in a temporary 'inactive' status, so that it can be reactivated when market or technology conditions improve, instead of being permanently plugged and abandoned. Eventually these wells may become orphaned.

Table 5.34: Summary environmental hazards and risk level for stage 5 well site abandonment

Processes/ technologies	**Environmental Aspects**	**Risk characterisation (with** expected management measures in place)			**Risk characterisation** (**without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
15. Post closure and abandonment							
15.1 Long-term well integrity and monitoring	Groundwater contamination	Extremely Rare	Minor	2 low	Extremely Rare	Moderate	4 low
	Surface water contamination	Rare	Minor	4 low	Rare	Moderate	6 moderate
	Releases to air (contribution to global warming)	Rare	Minor	4 low	Occasional	Minor	6 moderate
15.2 Relinquishing licences	Project completion - no significant risk associated with this activity, therefore it is not considered further.						

The list of processes and technologies assessed to have possible impact in stage 5 include:

15.1 Long-term well integrity and monitoring

This environmental impacts for this process are explored in greater detail in the following section.

5.6.2 Long-term well integrity and monitoring

5.6.2.1 Overview

Wells are abandoned post closure and plugged either by the operator or by the local authority if they are orphaned. There are often residual hydrocarbons in the reserve and there is a possibility that over time these hydrocarbons can leak from the well bore, if integrity is not ensured. This can lead to the pollution of surface and ground waters by hydrocarbon liquids and contributions to greenhouse gas emissions from leaking hydrocarbon gases.

Several studies on well integrity of active wells have been conducted, including Davies et al (2014), King & King (2013) and Ingraffea et al (2014). All concluded that while the probability of an individual-barrier failure (whereby one barrier fails but overall containment is maintained and no pollution is released) ranges from very low to several percent or higher for some types of wells (depending on factors such as age, location, etc.), full well-integrity failures resulting in pollution are very rare – roughly two to three orders of magnitude lower than single-barrier-failure rates (King & King, 2013). However, Davies et al (2014) stated that to their knowledge monitoring of abandoned wells does not take place in the UK or any other jurisdiction (e.g. Alberta, Canada) they know of, and less visible pollutants such as methane leaks are unlikely to be reported. It is therefore possible that well integrity failure may be more widespread than the presently limited data show. The impact of this lack of monitoring and the extent to which this may be applicable in other member states is not clear.

Ingraffea et al (2014) found that the likelihood of integrity failure may be up to 6 times higher in unconventional wells as compared to conventional wells, which was attributed to the high pressures associated with hydraulic fracturing. However, they do not specify whether this applies to either active or abandoned wells or both.

There is limited literature available on methane emissions from abandoned wells, but one study by Kang et al (2014) measured methane fluxes from 19 such wells in Pennsylvania. Three of these wells were found to be high emitters of methane and as a result they concluded that abandoned wells have the potential to contribute significantly to total global methane emissions, due to the large number of them worldwide.

5.6.2.2 Measures

Examples of measures which may be applied include:

- Regular pressure monitoring to determine well integrity.

As set out in Section 7, where such monitoring is carried out, this is generally done by operators (rather than authorities).

5.6.2.3 Issues

The risk levels for long term well integrity failure are presented in Table 5.35.

Table 5.35: Impacts and risks of long term well integrity failure

Main Environmental Aspects	Impacts	Risk Level
Groundwater contamination	Subsurface leaks of hydrocarbon fluids can occur, which result in fluids penetrating groundwater reserves. King & King (2013) found that if the well failure is in the subsurface, an outward leak is uncommon because of lower pressure gradient in the well than in outside formations. Subsurface leaks in oil and gas wells are therefore rare and generally result in exterior-formation salt water leaking into the well toward the lower pressure in the well, rather than hydrocarbons leaking out and penetrating groundwater.	2 low
Surface water contamination	Liquid hydrocarbons may leak from the mouth of the well bore, resulting in a contamination of surface waters.	4 low
Releases to air (contribution to global warming)	Well integrity failure can result in hydrocarbon gases (incl. methane) being released to the atmosphere and contributing to climate change. King & King (2013) found that when a total well-integrity failures occurs, gas is the most common fluid lost.	4 low

6. Risks and impacts of offshore activities

6.1 Overview

The following sections outline the identified risks for offshore activities. The identified risks both with and without expected mitigation measures are presented. Further details are provided in Appendix B.

Note that the summary tables below include both mitigated and unmitigated risks. The other tables refer only to the risk characterisation with expected management measures in place. For offshore activities, it is recognised that some environmental risks may be greater when the installation is located in challenging conditions such as areas with deeper waters, high winds, low temperatures and rough seas. Aspects for which risks after expected measures have been applied are likely to vary based on these conditions are noted in the risk assessment and an explanation included in a footnote.

6.2 Stage 1 Site identification and preparation

The first stage in the lifecycle is the identification of potential sites for production of oil and gas offshore. This involves desk-based tasks to review the existing state of knowledge for location of oil and gas fields based on the gridded blocks from section 2. Further information can then be gathered about the state of the sea-bed using gravimetric surveys and detailed information about sub-seabed geology from use of seismic surveys. These survey elements are used to develop leads and the placement of exploratory wells to assess the viability production of oil and gas. Therefore stage 1 will include:

1. Identification of resources
    a. Desktop studies
    b. Licensing
2. Surveys
    a. Gravimetric surveys
    b. Seismic surveys

A summary of risk characteristics for Stage 1 site identification and preparation is outlined in Table 6.1. Further details of the risk assessment can be found in Appendix B.

Table 6.1: Summary environmental hazards and risk for stage 1 site identification and preparation

Processes/ technologies	Environmental Aspect	Risk characterisation (**with** expected management measures in place)			Risk characterisation (**without** expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
1. Identification of resource (desktop study)							
1.1 Identifying target area for favourable geological conditions and licensing	Desk based task - no specific risks identified so not considered further.						

2. Surveys and conceptual model							
2.1 Gravimetric and seismic surveys of seabed to develop identification of leads	• Releases to air (local air quality impacts)	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Releases to air (contribution to global emissions for greenhouse gas)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Underwater noise in the marine environment (injury to animals)	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Underwater noise in the marine environment (disturbance to animals)	Likely	Slight	4 low	Highly likely	Slight	5 moderate

The list of processes and technologies assessed to have possible impact in stage 1 include:

1.1 Marine transport and fuel use for surveying.

2.1 Gravimetric and seismic surveys of seabed to develop identification of leads

Site identification will also include the drilling of exploratory wells called 'wild-cats'. As exploratory wells can be converted to production wells, all issues relating to wells and drilling are covered within life-cycle stage 2 (well design and construction).

6.2.1 Marine transport and fuel use for surveying

6.2.1.1 Overview

Following the desk based tasks it is necessary to carry out surveying of the potential offshore sites using shipping supplied with survey equipment. The use of shipping to carry out this activity will also mean the requirement for use of marine fuel oils to power the ships engines and will lead to exhaust emissions to air. These emissions present potential impacts to two receptors, namely local air quality effects from the release of air quality pollutants such as sulphur oxides (SO_x), oxides of nitrogen (NO_x) and volatile organic chemicals (VOCs); and contribution to emissions of greenhouse gases to the atmosphere.

6.2.1.2 Measures

The use of shipping within offshore oil and gas installations is unavoidable with multiple life-cycle stages including shipping elements. While the use of shipping to carry out key activities with regard to offshore oil and gas is a necessity there are a number of measures assumed to help limit the impacts on local air quality and international greenhouse gas emissions:

- The production of Environmental Statements as part of the planning for developing a site will typically include consideration of shipping emissions. This can include items such as the development of carbon footprint calculations to estimate overall impact of a given site and comparison to total offshore oil and gas contributions (Ffyne, 2014, and Edradour, 2012). Environmental statements can also include consideration of logistical aspects to limit the number of shipping journeys to the minimum required;
- The Marpol Convention under Annex VI places strict requirements on shipping to maintain low emissions of air quality pollutants such as SO_x and NO_x within fuels used (Marpol[50]). Furthermore as of the 1st January 2015 for those areas designated 'sulphur emission control areas (SECAs)', sulphur content in fuel must not exceed 0.1% wt/wt (EMSA 2010). This matches requirements under Directive 2005/33/EC which requires ships within EU ports to maintain sulphur content in fuel not above 0.1% wt/wt if not using electrical energy generation; and
- The International Panel on Climate Change (IPCC, 2007) stated that emissions of greenhouse gases from all shipping would be reduced by up to 30% in new ships and 20% in old ships through the adoption of new energy saving technology options. This includes applying current energy-saving technologies vis-à-vis hydrodynamics (hull and propeller) and machinery on new and existing ships. Savings could also be made through logistical options such as routing that ships use and speed of vessels, with reduction in speed equating to a reduction in greenhouse gas emissions.

6.2.1.3 Issues

The risk levels for marine transport are presented in Table 6.2.

Table 6.2: Risks and impacts of marine transport

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	The use of shipping for offshore oil and gas installations is a necessity, which will generate emissions to air from fuel use of vessels. The effects on local air quality and concentrations within the air and deposition to surface water are affected by a number of variables, including weather conditions. The measures outlined to maintain low sulphur content and limit shipping to a minimum will help mitigate this risk.	3 low
Releases to air (contribution to international greenhouse gas emissions)	The use of shipping for offshore oil and gas installations is a necessity, which will generate emissions to air from fuel use of vessels. While oil and gas operations will only make up a proportion of all international shipping that occurs, the contribution from this sector to international greenhouse gas emissions should not be under-estimated. The IPCC (2007) comments on energy-saving equipment measures that can be introduced to cut emissions significantly. However the same reference also recognises that market penetration of such measures into the shipping fleet is still relatively low and that more needs to be done to ensure uptake of these options.	5 moderate

[50] Marpol Convention, Annex VI
http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

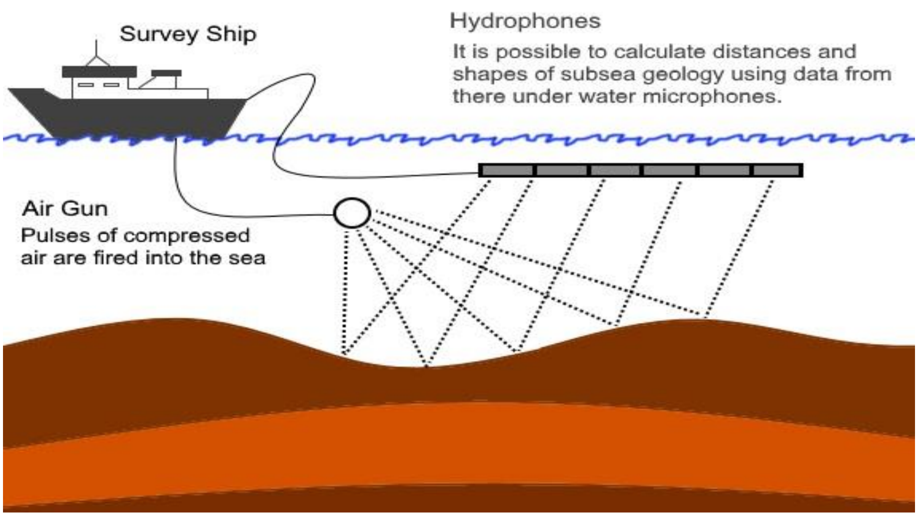
6.2.2 Gravimetric and seismic surveys

6.2.2.1 Overview

The use of gravimetric and in particular seismic surveys are used to help provide information about the sub-seabed geology and identification of oil and gas deposits for further production. The process of using seismic surveys involves shipping vessels towing air guns which fire compressed air cells into the sea every 10-12 seconds (NRDC, 2010), and use of sound boom equipment to detect the resulting echo. An illustration of this process is provided in Figure6.2. This process can penetrate deep into the subsea geology and provide valuable information for identification of oil and gas deposits. However it can also present a serious concern for sub-sea seismicity with Weilgart (2013) stating that the use of seismic surveys is capable of raising ambient background noise by 20 decibels.

The consequences for marine life, particularly the cetacean family (whales, dolphins, and porpoise) which uses sonar is of high importance. There is a distinction between the levels of seismicity capable of causing physical injury to marine mammals and levels of seismicity which cause disturbance and potentially behavioural change. The JNCC guidelines provide further information on risk management measures to ensure that seismicity is kept well below levels that can cause physical injury.

Figure 6.1: Illustration of Seismic Survey



Based on Reference BP, 2008

6.2.2.2 Measures

A wide variety of measures are open to operators to limit the impact of seismic surveys; these measures should ideally be used in combination:

- Under the EU habitats directive (92/43/EEC) a list of protected marine species are identified including cetaceans. Furthermore under the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) cetaceans are protected species. During the planning phase and development of Environmental Statements, operators should review the survey area for known presence of protected species and make every effort to avoid conducting surveys during known breeding seasons. In the UK, the JNCC provide atlases of known species for North West waters (http://jncc.defra.gov.uk/page-2713);

- Marine Mammal Observers (MMO), also known as 'whale watchers', are trained personnel who are used to scout the survey area while at sea with the shipping vessel before surveying takes place (JNCC 2010; ASCOBANs, 2010). If protected species are identified within proximity to the survey vessel (500 metres), seismic surveys are delayed until the area is clear once more (JNCC, 2010);
- Passive Acoustic Monitoring (PAM) is sound monitoring equipment used below the surface of the sea to detect 'whale noise' within close proximity of the survey vessel. Again if cetaceans are detected in close proximity surveying are delayed until the area is clear once more;
- 'Soft-start' – refers to the early stages of seismic surveying where the equipment should begin with low energy pulses building slowly to full operational capacity at the height of surveying. It is intended that commencing in this fashion is less shocking for marine life within range of the survey area and allows marine species to evade the surveying before it reaches full operational capacity (JNCC, 2010);
- A defined survey window of 30 or 60 minutes used to carry out surveys with a defined break between survey windows to allow marine habitats to recover from surveying operations;
- Maintenance and design of equipment to avoid excessive high frequency seismic waves, which might include the use of abatement equipment such as baffles, (JNCC, 2010); and
- Underwater noise mitigation technologies, including noise mitigation screens (NMS), hydro sound dampers and air bubble curtains (ACCOBAMS, 2013).

6.2.2.3 Issues

The risk levels for seismic surveys are presented in Table 6.3.

Table 6.3: Risk and impacts of seismic surveys

Main Environmental Aspects	Impacts	Risk Level
Underwater noise in the marine environment (potential to cause physical injury)	Seismic surveys require the use of compressed air guns to fire pulses into the seabed to gather information about subsea geology. The equipment used can generate noise 100,000 times louder than air craft (Oceana, 2013), so the potential to cause physical injury to marine mammals and fish is real. DNV (2007) estimate that harm is caused to creatures <5m from the gun and serious injuries at <1.5m. Fish in the early stage of life are particularly vulnerable. However, this issue is well recognised internationally and a large range of measures are in place to control the risk including the JNCC guidelines (2010) and advice from ACCOBAMS (2013) and ASCOBANS (2010. Assuming the measures quoted are adopted the potential to cause physical injury is greatly reduced.	4 low
Underwater noise in the marine environment (potential to cause disturbance to marine life)	The distinction between physical injury and disturbance that potentially causes behavioural change is important. A number of organisations question the impact of seismic surveys on effecting cetacean populations (Oceana 2013 and NRDC, 2010); evidence linking activity such as 'beaching' of whales with seismic surveys is still the subject of ongoing investigation. It has been documented that adult fish demonstrate reactions to soundwaves at distances of up to 30km, which have the potential to	4 low

Main Environmental Aspects	Impacts	Risk Level
	interfere with spawning cycles (DNV, 2007). Again the risks of seismic surveys to marine populations are well recognised internationally and a variety of measures are available to control the risk.	

6.3 Stage 2 Well design and construction

6.3.1 Summary of environmental risks

The completion of lifecycle stage 1 will finalise the identification of potential oil and gas deposits for production. The drilling of exploratory wells can occur within lifecycle stage 1, but in reality the exploratory well is often also used to complete the main well for production of oil and gas and so has been discussed within life cycle stage 2. This stage will include all of the onshore tasks to plan the well, logistical elements over the type of rig/platform that will be needed and any onshore construction phase. It then includes the following key sub-stage processes and technologies:

3. Planning phases including onshore construction
4. Installation of the drilling rig
    4.1 Transport of drilling rig to site
5. Well drilling
    5.1 Positioning of drilling apparatus on seabed
    5.2 Drilling using water based and oil based muds
    5.3 Handling of drill cuttings
    5.4 Cementing and casing
6. Well completion
    6.1 Well-bore clean up
    6.2 Introduction of completion fluids

A summary of risk characteristics for Stage 2 well design and construction are outlined in Table 6.4. Further details of the risk assessment can be found in Appendix B

Table 6.4: Well design and construction.

Processes / technologies	Environmental Aspect	**Risk characterisation** (with expected management measures in place)			**Risk characterisation** (without expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
3. Well design (desktop study)							
3.1 Planning and design for well, including rig type and logistics	Desk based task - no specific risks identified so not considered further.						

4. Installation of drilling rig (also covers exploratory wells)							
4.1 Transport of drilling rig, supply vessels	• Releases to air (local air quality impacts)	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Releases to air (contribution to global emissions for greenhouse gas)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
	• Discharges to sea (containment failure on shipping)[51]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Discharges to sea (containment failure on rig)[51]	Rare	Slight	2 low	Rare	Minor	4 low
5. Well drilling (also covers exploratory wells)							
5.1 Positioning of apparatus on seabed for exploratory drilling	• Seabed disturbance[52]	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
	• Underwater noise in the marine environment • (disturbance to animals)	Likely	Slight	4 low	Highly likely	Slight	5 moderate
	• Marine biodiversity impacts (introduce foreign species)	Rare	Moderate	6 moderate	Likely	Moderate	12 high
5.2 Drilling using water based mud (WBM)/oil based mud (OBM)	• Seabed disturbance	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Releases to air (local air quality impacts)	Occasional	Slight	3 low	likely	Minor	8 moderate
	• Releases to air • (contribution to global emissions for greenhouse gas)	Likely	Slight	4 low	Highly likely	Minor	10 high
	• Underwater noise in the marine environment (disturbance to animals)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Discharges to sea (planned) – impacts to marine ecosystems	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (planned) – impacts to water	Occasional	Slight	3 low	Occasional	Minor	6 moderate

[51] In rough seas and high winds, the risk of a containment failure may increase as there are narrower margins for error when loading and unloading from the rig.

[52] In deeper waters, the seabed disturbance caused by positioning apparatus on the seabed may be increased, as the placement is less accurate.

	quality						
	• Discharges to sea (planned) – fouling seabed	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Discharges to sea (accidental) – Tier III* – Major incident – impacts to marine environment	Rare	Catastrophic	10 high	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – impacts to coastal environment	Rare	Catastrophic	10 high	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – impacts to water quality	Rare	Catastrophic	10 high	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – fouling seabed marine environment	Rare	Moderate	6 moderate	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – impacts to marine environment	Rare	Major	8 moderate	Likely	Major	16 very high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – impacts to coastal environment	Rare	Major	8 moderate	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – impacts to water quality	Rare	Major	8 moderate	Likely	Major	16 very high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – fouling seabed	Rare	Minor	4 low	Occasional	Moderate	9 moderate
	• Discharges to sea (accidental) – Tier I* – Minor incident – impacts to marine environment	Occasional	Minor	6 moderate	Likely	Moderate	12 high

	• Discharges to sea (accidental) – Tier I* – Minor incident – impacts to coastal environment	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea (accidental) – Tier I* – Moderate incident – impacts to water quality	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) – Tier I* – Minor incident – fouling seabed	Rare	Slight	2 low	Rare	Minor	4 low
5.3 Handling of drill cuttings	• Discharges to sea (planned) – impacts to marine ecosystems	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (planned) – impacts to water quality	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (planned) – fouling seabed	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
5.4 Cementing and casing	• Discharges to sea (accidental) – impacts to marine ecosystems[53]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental – impacts to water quality[53]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) – fouling seabed[53]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Underwater noise in the marine environment (disturbance to animals)	Rare	Slight	2 low	Occasional	Slight	3 low
6. Well completion							
6.1 Well-bore clean up	• Releases to air – flaring of gas (local air quality impacts)	Likely	Slight	4 low	Highly likely	Minor	10 high

[53] In rough seas, high winds and low temperatures the risks of accidental discharges to sea may increase as there is greater stress put on containment equipment and lower margins for operator error during drilling, cementing and casing.

	• Releases to air – flaring of gas (contribution to global emissions for greenhouse gas)	Likely	Slight	4 low	Highly likely	Minor	10 high
	• Discharges to sea – drop-out from flaring – impacts to marine ecosystems	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – drop-out from flaring - impacts to water quality	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – drop-out from flaring - fouling seabed	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Discharges to sea (accidental) – leak from well - impacts to marine ecosystems[54]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental – leak from well - impacts to water quality[54]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) – leak from well -fouling seabed[54]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
6.2 Introduction of completion fluids	• Discharges to sea (accidental) – leak from well - impacts to marine ecosystems[54]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental – leak from well - impacts to water quality[54]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) – leak from well -fouling seabed[54]	Occasional	Slight	3 low	Occasional	Minor	6 moderate

*The explanation of tiered levels of hazard and impact is provided in under the process titled '5.2 Drilling (with the use of water based muds and oil based muds)' in this section of the report. For all of these aspects, the likelihood of accidental discharge may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error during drilling, drill cuttings management, cementing and casing.

The list of processes and technologies assessed to have possible impact in stage 2 are:

[54] In deeper waters there may be a greater risk of accidental discharges to sea during well completion, as a much greater length of the well bore is exposed to the ocean.

4.1 The transport of the drilling rig to the well site;

5.1 Positioning of apparatus on seabed for exploratory drilling;

5.2 Drilling with the use of water based muds and oil based muds;

5.3 Handling of cuttings which may be contaminated with oil based muds;

5.4 Cementing of well casing;

6.1 Well-bore clean up; and

6.2 Introduction of completion fluids.

Subsequent sections discuss and outline each environmental impact for the processes and technologies in further detail.

6.3.2 Transport of the drilling rig to the well site

6.3.2.1 Overview

The movement of the drilling rig from onshore facilities to the well site offshore will depend upon the type of vessel selected to carry out the exploratory drilling. Exploration vessels will be more mobile than installations used during production, with the capacity to drill multiple wells over a survey area during the exploration phase. The use of shipping vessels and fuel to power the engines will generate air emissions for both air quality pollutants (SO_x, NO_x, and VOCs) and greenhouse gases. These are similar issues with similar measures already described within 'marine transport' under section 3.5.1. No further discussion is provided here for this aspect.

The other associated risk with this process / technology relates to losses of cargo while at sea or bunkered, particularly oil due to loss of containment, collision etc.

6.3.2.2 Measures

Measures assumed to be in place include:

- Use of double hulled shipping to protect cargo during collisions;
- Strategic placement of cargo within the hold, e.g. ballast tanks on the outside nearest the hull, bunkered oil in the core of the ship. This would put greater distance between the cargo and skin of the ship during a collision;
- Maintenance and manual check of containment vessels before travelling to ensure continuity and risk for containment failure; and
- Monitoring of containment vessels to identify containment loss from e.g. valves as soon as possible.

6.3.2.3 Issues

The risk levels for transport of the drilling rig to the well site are presented in Table 6.5.

Table 6.5: Risk and impacts of transporting the drilling rig to the well site

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality)	The use of shipping for offshore oil and gas installations is a necessity, which will generate emissions to air from fuel use of vessels. The effects on local air quality and concentrations within the air and deposition to surface water are affected by a variety of variables, including weather conditions. The measures outlined to maintain low sulphur content and limit shipping to a minimum will help mitigate this risk.	3 low

Main Environmental Aspects	Impacts	Risk Level
Releases to air (contribution to international greenhouse gas emissions)	The use of shipping for offshore oil and gas installations is a necessity, which will generate emissions to air from fuel use of vessels. While oil and gas operations will only make up a proportion of all international shipping that occurs, the contribution from this sector to international greenhouse gas emissions should not be under-estimated. The IPCC (2007) comments on energy-saving equipment measures that can be introduced to cut emissions significantly. However the same reference also recognises that market penetration of such measures into the shipping fleet is still relatively low and that more needs to be done to ensure uptake of these options.	5 moderate
Discharges to sea (containment failure on shipping)	Transport of the drilling rig will be carried out using multiple shipping vessels which will carry cargoes of bunkered oil for fuel use on the vessel. The identified risk relates to the loss of containment either through collision or loss of containment for the storage vessel on-board. The measures identified go some way to prevent the risk of discharge to sea, but based on shipping more generally the potential for loss of bunkered oil to sea has been ranked as 'occasional'.	6 moderate
Discharges to sea (containment failure on rig)	The drilling rig itself, depending on the choice of rig selected will carry a combination of chemicals and oil based materials such as hydraulic fluids. However the likely quantity involved compared to shipping vessels is likely to be lower, and the potential for collision / loss of containment would also be lower on the basis of 1 drilling rig versus up to 4 tug boats towing the rig.	2 Low

6.3.3 Positioning of apparatus on the seabed for exploration drilling

6.3.3.1 Overview

Exploration vessels will be based around the Mobile Offshore Drilling Units (MODU) archetype which typically involves a mobile vessel which is kept stationary relative to the seabed by either anchoring, using directional positioning (DP) thrusters or attached to the seafloor by jack-up legs The use of steel templates are placed on the seabed and held in place using piling to help guide the drilling equipment. The use of a Derrick on the topside of the drill rig may also be applied to help steady and guide the drilling process. The use of this apparatus will be less intrusive than the production stage with installation of platforms and seabed networks of equipment. However during the exploration phase multiple wells will be drilled adding to cumulative effects from this part of the process. The key environmental aspects identified for this process include:

- Seabed disturbance from the placing of equipment on the seabed, anchorage of the drilling vessel and discharges of drill cuttings. Cold water coral reefs and sponge communities are particularly sensitive to these aspects. If applicable, an EIA will cover sensitive species / communities and make provisions to avoid operations where impact is likely;
- Underwater noise generated from wellhead installation (e.g. piling activities) - The potential issues and measures to mitigate noise are similar to those described for

'seismic surveys' in section 6.1.2. Further explanation is provided under that heading;

- One key difference between seismic surveys and securing of the rig is in the type of noise. Seismic surveys involve sonic pulses fired into the sea bed, while piling activities generate 'hammering' noises. Both types of sound can cause disturbance to marine life due in part to the short violent bursts of sound produced. Other undersea equipment will typically produce a continuous humming noise which has less impact. On that basis the level of severity ranges from seismic surveys at the 'high' end to undersea equipment at the 'low' end, and piling or rock dumping between these two extremes; and
- Effects on marine biodiversity as a result of changing the substrate of the seabed (soft sands to hard structures) and potentially foreign species attached to the rig if moved from one well site to another.

6.3.3.2 Measures

The measures assumed to be in place are listed below chronologically to match the order of the environmental aspects identified above:

Seabed disturbance

- The placing of equipment on the seabed will cause disturbance to the seabed and flora and fauna that inhabit the surface layers. To mitigate this impact environmental statements for planning need to assess the seabed for the level of disturbance and recovery time. The selection of rig type and required surface area can be important to limit disturbance, and a number of the environmental statements reviewed (Ffyne 2014, Mariner 2012, and Kew 2012) discuss options such as:
    - Mapping anchoring points for rigs and shipping vessels which can be used again to avoid further disturbance;
    - Avoidance of protected areas for placement of rigs; and
    - Environmental estimates for recolonisation times after completion of work.
- For activities such as 'rock dumping' to secure the rig in place can cause further disturbance to the sea bed. Again during the planning phase selection of rig type/securing to seabed is important, but in the case of rock dumping, the size of rocks is important and use of guided pipe to ensure accurate positioning can limit impact.

Noise

- The majority of measures to counter noise match those for seismic surveys which are discussed under 'seismic surveys' in section 6.1.2. Additional measures for securing drilling rigs relate to 'soft-start' for piling. Similarly to the soft-start for seismic equipment, piling activity begins with a reduced level of activity building to full operational strength. This allows marine life in proximity to evade the area before full operational strength is reached.

Marine biodiversity

- Management of planning for use of equipment particularly ballast tanks to ensure that water is only taken and returned to the sea at the well site in use.

6.3.3.3 Issues

The risk levels for positioning of the drilling rig on the seabed are presented in Table 6.6.

Table 6.6: Risk and impacts of positioning apparatus on the seabed.

Main Environmental Aspects	Impacts	Risk Level
Seabed disturbance	Seabed disturbance from the placing of drilling rigs and equipment on the seabed, drill vessel anchorage and the discharge of drill cutting is inevitable. However measures are in place to help limit the scale of the impact and to protect sensitive areas of seabed from damage. Due to the highly likely basis of the potential impact the overall risk rating is generally deemed to be moderate. Sensitive biota such as sponge or cold water coral communities are expected to take some time to recover from disturbances.	5 moderate
Underwater noise in the marine environment (potential to cause disturbance to marine life)	The distinction between physical injury and disturbance that potentially causes behavioural change is important. Seismic surveys within stage 1 have been identified as having the greatest potential to cause physical injury to marine life from noise across the whole off-shore installation life cycle. However activities such as piling and rock dumping still have the potential create sufficient noise levels as to have effects on marine species. The risk ranking of generally low is awarded on the basis that all of the measures identified in stage 1 and 2 are in use.	4 low
Marine biodiversity impacts (introduce foreign species)	The consequences of introducing foreign species into new waters can have significant impacts depending on how quickly and aggressively the foreign species takes hold of a new environment. Care is needed to avoid introduction of foreign species for managing water in ballast tanks and species attached to the rig itself if moved from one location to another. Due to the potential severity of the consequence of introducing foreign species the risk ranking is judged as generally moderate.	6 moderate

6.3.4 Drilling (with the use of water based muds and oil based muds)

6.3.4.1 Overview

This process covers the well drilling phase of stage 2, which will be carried out making use of lubricating materials to assist in the completion of drilling. The use of 'sweeps' (water plus bentonite pellets), 'water based mud' and 'oil based mud' will be selected based on desired rheology (flow) with all three typically used in practice at different stages of drilling. It is also necessary to recognise that this process is carried out under pressurised conditions with use of closed systems to manage the flow of material into and out of the well as drilling progresses.

The risk assessment presented here will include those risks that can occur from planned and unplanned activities, but also accidents which can potentially have much more serious consequence. In developing the risk assessment to cover 'accidents' which can include a variety of incidents, the approach has adopted the guidance presented by IPIECA (2007). This was chosen because it covers the most universally accepted classification of accidental risk in the oil and gas industry. It was developed in the shipping industry and then became an IMO convention and is widely recognised by industry, academia and numerous authorities including regulators and coastguards. The system provides a framework for determining the level of preparation required for response to small, medium and large events. Under the guidance, accidents are split into three tiers:

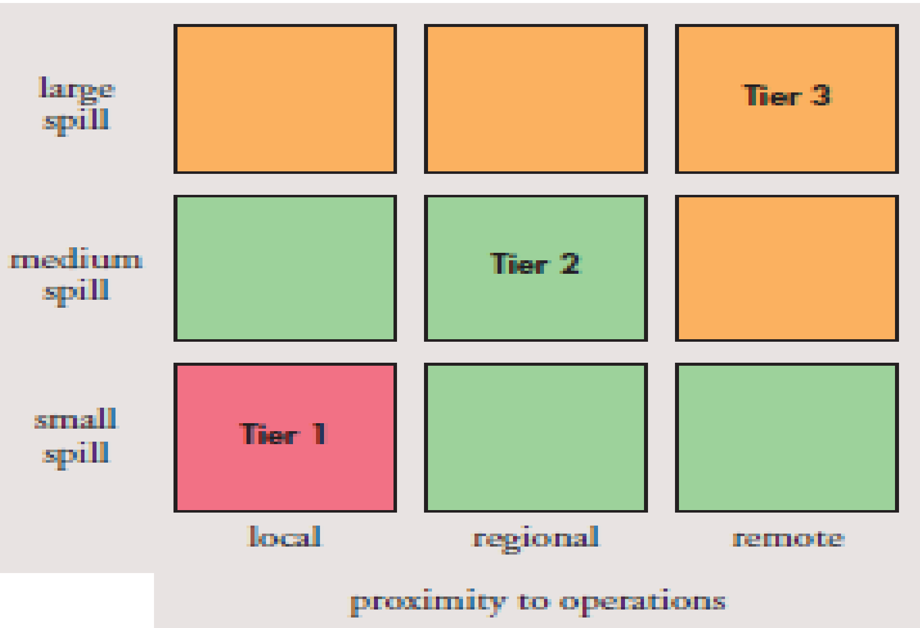
Tier 1: events are likely to be relatively small and/or affect a localised area. They may be dealt with best using local resources, often prepositioned close by, and managed by the operator.

Tier 2: events are more diverse in their scale and by their nature involve potentially a broad range of impacts and stakeholders. Correspondingly, Tier 2 response resources are also varied in their provision and application. Management responsibilities are usually shared in a collaborative approach and a critical feature is the integration of all resources and stakeholders in the response efforts.

Tier 3: events are rare but have the potential to cause widespread damage, affecting many people and overwhelming the capabilities of local, regional and even national resources. Tier 3 response resources are concentrated in a relatively few locations, held in readiness to be brought to the country when needed. Such significant events usually call for the mobilisation of very substantial resources and a critical feature is their rapid movement across international borders and the integration of all resources into a well organised and coordinated response.

See also the diagram provided in Figure 6.2

Figure 6.2: Tiered response levels



Reference: IPIECA, 2007

The environmental aspects likely to be effected by this process will cover:

- Seabed disturbance – The details for seabed disturbance are more fully discussed under the section titled 'Positioning of the drilling rig on the seabed' in section 6.3.3. The associated risks and measures will be similar to that process. No further discussion is given in this section;
- Releases to air from fuel emissions related to drilling equipment;
- Noise from drilling activities – The details of noise from offshore activities and the measures available to operators will be the same as those described for 'seismic surveys' in section 6.2. No further discussion is given in this section;
- Planned discharges to sea; and
- Accidental events.

6.3.4.2 Measures

The potential measures are listed below chronologically to match the order of the environmental aspects identified above:

Releases to air from fuel emissions (non-shipping)

- Best Available Technology (BAT) assessments for equipment used onsite, including development of carbon footprint calculations within Environmental Statements to assess impact; and
- Use of low-sulphur and ultra-low sulphur fuels for use in engines.

Planned discharges to sea

- Use of chemicals for drilling operations selected on the basis of low hazard/risk[55];
- Dispersion modelling and risk impact assessment for materials released to environment; and
- Separation of drilling mud from cuttings that are to be discharged using a shaker during drilling.

Accidental events

- Planning based measures:
    - Environmental Statement with identification of risks and oil spill modelling specific to the site;
    - Emergency plans, including spill clean-up procedures and accident logs;
    - Dedicated oil-spill response crews contracted to respond at short notice; and
    - Training for all personnel onsite.
- Technical based measures:
    - The use of drilling mud to balance the pressure of well fluids, cool the drill bit and extract cuttings to the surface (NORSOK D-10);
    - Blow-Out Preventers (BOPs) – large specialised valves used to seal wells in the event of a blowout;
    - Well Kill – The process of circulating heavy fluids into the well in order to suppress unexpected pressure increases caused by formation fluids. After a BOP has activated, kill fluids can be used to clear out blowout fluids and regain control of the well;
    - Drilling Relief wells - these intersect a well that has experienced a blowout. Cement or another heavy liquid is pumped down them to block the defective well;
    - Capping options for well; and
    - Bunding for smaller scale storage of fuel and chemicals.

[55] For example, those on the OSPAR list of substances that 'Pose little or no risk' to the environment (PLONOR) (OSPAR, 2012b) or under the "zero discharge principle" for the HELCOM region which requires cessation of discharges of all "black" and "red" listed chemicals under the Baltic Sea Action Plan. Under the Barcelona Convention, discharge of harmful or noxious substances is either prohibited (Annex I) or requires a permit (Annex II); development of guidelines specifying the limitations or prohibitions for use of chemicals has been recommended. The REACH and CLP Regulations will also significantly affect choice/use of chemicals across Europe. However, there remain differences in approach amongst Member States in terms of chemical selection/substitution (Chemical Watch, 2014).

6.3.4.3 Issues

The risk levels for drilling are presented in Table 6.7.

Table 6.7: Risk and impacts of drilling

Main Environmental Aspects	Impacts	Risk Level
Seabed disturbance	The main impact identified within this process is impact upon the seabed from the drilling operation itself. The likely affected area will be small based on the size of the well bore. Secondary issues could relate to any loss of drilling muds smothering the sea-bed. However the contained nature of drilling means the risk of losing drilling muds should be limited.	3 low
Releases to air (local air quality)	The use of shipping for offshore oil and gas installations is a necessity, which will generate emissions to air from fuel use of vessels. The effects on local air quality and concentrations within the air and deposition to surface water are affected by a number of variables, including weather conditions. The measures outlined to maintain low sulphur content and limit shipping to a minimum will help mitigate this risk.	3 low
Releases to air (contribution to international greenhouse gas emissions)	The use of shipping for offshore oil and gas installations is a necessity, which will generate emissions to air from fuel use of vessels. While oil and gas operations will only make up a proportion of all international shipping that occurs, the contribution from this sector to international greenhouse gas emissions should not be under-estimated. The IPCC (2007) comments on energy-saving equipment measures that can be introduced to cut emissions significantly. However the same reference also recognises that market penetration of such measures into the shipping fleet is still relatively low and that more needs to be done to ensure uptake of these options.	4 low
Underwater noise in the marine environment (potential to cause disturbance to marine life)	Underwater noise generated during the drilling phase relates to the 'humming' noise generated by pumping equipment and drill machinery. Noise generation from these sources will have less impact than piling and rock dumping during installation and significantly less impact than seismic surveys during life cycle stage 1.	2 low
Discharges to sea (planned) damage to marine ecosystems	The use of the measures identified including use of low hazard/risk chemicals, limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[56] of these materials within sea water will continue to reduce the risk of impact in the short term.	3 low
Discharges to sea (planned) damage	The use of the measures identified including use of low hazard/risk chemicals, limits on hydrocarbon content of	3 low

[56] The risk assessed here refers to immediate impacts. Cumulative impacts (e.g. the impact of multiple installations in a particular area) could not be examined as part of this study. It should therefore be noted that impacts may be different depending on the situation. For example, accumulation of discharges to sea from numerous installations may be expected to have greater adverse impacts on the environment due to less dilution effect within an area. This would be applied to all dilution impacts. Refer to section 1.4.3 on cumulative impacts.

Main Environmental Aspects	Impacts	Risk Level
to water quality	released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[57] of these materials within sea water will reduce concentrations affecting water quality.	
Discharges to sea (planned) seabed fouling	The main impacts on seabed fouling is where solid material such as drilling muds and cuttings smothers the sea bed affecting the benthic species that live in the surface layers of the seabed. Effects can be significant killing all life in the surface layers. However on completion of the process the affected area is expected to recover quickly with re-population from surrounding areas.	6 moderate
Impacts to marine ecosystems (accidental) Tier III	Accidental release of large quantities of oil to sea would be likely to have severe impact on marine species. The severity would be such that it could be foreseen that the impact would take a significant amount of time spanning years for the full recovery of the affected marine ecosystems. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier III event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier III event occurring during production was judged to be 'Rare'.	10 high
Impacts to coastal environments (accidental) Tier III	The accidental release of large quantities of oil to sea would have a high potential for those materials to reach the coastline where the impacts would be extremely severe for not only marine species but avian and terrestrial species within the near shore. The potential damaged caused could have long term (years) effect along the affected coastline with recovery of ecosystems expected to be slow. In some cases such damage may mean that ecosystems do not fully recover to pre-incident conditions. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier III event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier	10 high

[57] Refer to section 1.4.3 on cumulative impacts.

Main Environmental Aspects	Impacts	Risk Level
	III event occurring during production was judged to be 'Rare'. Due to the large quantities of oil involved in a tier III spill, damage to the coastline is unavoidable, particularly as some rigs in Europe are located close to the shore. For this reason, the likelihood of this aspect is judged to be the same as impacts to marine systems and water quality.	
Impacts to water quality (accidental) Tier III	While hydrocarbons will emulsify and degrade within marine conditions for a tier III event the quantities of oil involved would have severe impact upon the general water quality within the marine environment. The degradation and breakdown of hydrocarbons would be expected to have a strongly negative affect for chemical oxygen demand affecting the ability of seawater to support marine life. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier III event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier III event occurring during production was judged to be 'Rare'.	10 high
Seabed fouling (accidental) Tier III	The potential for hydrocarbon spillages to reach the seabed is less clear, but given the quantities involved the potential for seabed fouling should be considered a risk. This would include contamination of marine sediments which have knock-on effects for benthic species that live within them. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier III event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier III event occurring during production was judged to be 'Rare'. Due to the large quantities of oil involved in a tier III spill, damage to the seabed is unavoidable, particularly as some rigs in Europe are located in shallower waters. For this reason, the likelihood of this aspect is judged to be the same as impacts to marine systems and water quality.	6 moderate
Impacts to marine ecosystems (accidental) Tier	The IPIECA definition states that Tier II accidents will cover a more diverse set of incidents which have lower severity than Tier III. In practice for drilling the greatest risk is	8 moderate

Main Environmental Aspects	Impacts	Risk Level
II	related to a critical failure if the well releases thousands of litres of oil to the sea. A Tier II incident may cover a similar incident but one that is brought under control more quickly resulting in a smaller quantity lost. However at Tier II level the impacts for marine species would be severe with both short term impact and longer term (months/years) effects to fully recover. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier II event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier II event occurring during production was judged to be 'Rare'.	
Impacts to coastal environments (accidental) Tier II	For Tier II incidents the quantity of hydrocarbons lost are still sufficient to make the possibility of reaching coastlines possible. The impact on marine, avian and terrestrial species at the near shore would be severe, with long term impacts and ecosystems likely to be slow to recover from the consequence of the incident. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier II event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier II event occurring during production was judged to be 'Rare'. Due to the large quantities of oil involved in a tier II spill, damage to the coastline is likely, particularly as some rigs in Europe are located close to the shore. For this reason, the likelihood of this aspect is judged to be the same as impacts to marine systems and water quality.	8 moderate
Impacts to water quality (accidental) Tier II	While hydrocarbons will emulsify and degrade within marine conditions for a tier II event the quantities of oil involved would have moderate impact upon the general water quality within the marine environment. The degradation and breakdown of hydrocarbons would be expected to have a strongly negative affect for chemical oxygen demand affecting the ability of seawater to support marine life. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this	8 moderate

Main Environmental Aspects	**Impacts**	**Risk Level**
	reason the frequency of a tier II event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier II event occurring during production was judged to be 'Rare'.	
Seabed fouling (accidental) Tier II	The fouling of seabed relates to the smothering of surface layers which affect benthic communities as well as potential toxic effects from the material discharged. At tier II level the potential for quantities of discharged oil reaching the seabed are more limited with the greatest quantities remaining in the water column. Impacts for seabed fouling are considered to be more limited with a risk rating of generally low. According to OGP (2010), the probability of a blowout occurring during *exploration/development drilling* is between $6.0x10^{-5}$ and $1.9x10^{-3}$ per well drilled. For this reason the frequency of a tier II event occurring during drilling was judged to be 'rare'. During *production*, the annual blowout frequency per producing well (inclusive all well intervention) is 4.28 x 10-5 (Sintef Blowout database - Scandpower, 2013). This corroborates with estimate given in OGP (2010) that the probability of a blowout occurring from a producing well is 3.9x10-5 per well. For this reason, the frequency of a tier II event occurring during production was judged to be 'Rare'. Due to the large quantities of oil involved in a tier II spill, damage to the seabed is unavoidable, particularly as some rigs in Europe are located in shallower waters. For this reason, the likelihood of this aspect is judged to be the same as impacts to marine systems and water quality.	4 low
Impacts to marine ecosystems (accidental) Tier I	Tier I accidents represent those with the highest frequency but lowest severity. The accidental discharge of drainage systems in this case may include waters contaminated with hydrocarbons or production chemicals. The quantities involved would be expect to be more limited but have the potential to still cause significant impact on marine species. According to OGP (2010), the probability of a well release occurring during *exploration/development drilling* is between $4.9x10^{-4}$ and $1.6x10^{-2}$ per well drilled. For this reason the frequency of a tier I event occurring during drilling was judged to be 'occasional'. During *production*, the OGP (2010) estimate that the probability of a well release occurring is between $2.9x10^{-6}$ and $1.1x10^{-5}$ per well. For this reason, the frequency of a tier I event occurring during production was judged to be 'Rare'.	6 moderate
Impacts to coastal environments	For Tier I accidents the quantities of material involved would be expected to be smaller than the major spillages described in earlier processes. The potential for discharged	4 low

Main Environmental Aspects	Impacts	Risk Level
(accidental) Tier I	material to reach the coastline is more limited, while impact would be expected to be more significant. However the because the frequency and consequence of the incident would be lower than in the Tier II case. According to OGP (2010), the probability of a well release occurring during *exploration/development drilling* is between $4.9x10^{-4}$ and $1.6x10^{-2}$ per well drilled. For this reason the frequency of a tier I event occurring during drilling was judged to be 'occasional'. However, due to the small quantities of fluid involved in a Tier I spill, the chances of the spill reaching the shoreline are reduced, the likelihood of coastal impacts *during drilling* are therefore judged to be 'rare'. During *production*, the OGP (2010) estimate that the probability of a well release occurring is between $2.9x10^{-6}$ and $1.1x10^{-5}$ per well. For this reason, the frequency of a tier I event occurring during production was judged to be 'Rare'. However, due to the small quantities of fluid involved in a Tier I spill, the chances of the spill reaching the shoreline are reduced, the likelihood of coastal impacts *during production* are judged to be 'extremely rare'.	
Impacts to water quality (accidental) Tier I	For Tier I accidents the quantities of material involved would be expected to be smaller than the major spillages described in earlier processes. The effects on water quality would be expected to be short lived with minor impact. According to OGP (2010), the probability of a well release occurring during *exploration/development drilling* is between $4.9x10^{-4}$ and $1.6x10^{-2}$ per well drilled. For this reason the frequency of a tier I event occurring during drilling was judged to be 'occasional'. During *production*, the OGP (2010) estimate that the probability of a well release occurring is between $2.9x10^{-6}$ and $1.1x10^{-5}$ per well. For this reason, the frequency of a tier I event occurring during production was judged to be 'Rare'.	3 low
Seabed fouling (accidental) Tier I	The impact for seabed fouling relates to smothering of surface layers where benthic species live. For tier I accidents where the likely discharged material is drainage waters contaminated with hydrocarbons or chemical wastes, the likelihood for seabed fouling is relatively low. According to OGP (2010), the probability of a well release occurring during *exploration/development drilling* is between $4.9x10^{-4}$ and $1.6x10^{-2}$ per well drilled. For this reason the frequency of a tier I event occurring during drilling was judged to be 'occasional'. However, due to the small quantities of fluid involved in a Tier I spill, the chances of the oil reaching the seabed are reduced, the likelihood of seabed fouling *during drilling* is	2 low

Main Environmental Aspects	Impacts	Risk Level
	therefore judged to be 'rare'. During *production*, the OGP (2010) estimate that the probability of a well release occurring is between 2.9x10^{-6} and 1.1x10^{-5} per well. For this reason, the frequency of a tier I event occurring during production was judged to be 'Rare'. However, due to the small quantities of fluid involved in a Tier I spill, the chances of the oil reaching the seabed are reduced, the likelihood of seabed fouling *during production* is therefore judged to be 'extremely rare'.	

6.3.5 Handling of Drill cuttings

6.3.5.1 Overview

The drilling process will generate drill cuttings brought back to the surface of the topside through the use of drilling muds. These cuttings will largely represent the natural geology of the seabed from whence they came. However it is also possible for the cuttings collected to be contaminated with both the residues of the drilling muds (including oil based drilling muds) and any hydrocarbons from the well itself. For this reason the cuttings gathered will need further processing. Provided the oil content of cuttings meets the international regulations under OSPAR (<1% OBF by dry weight), HELCOM, Barcelona Convention (noting that these requirements vary) and Marpol they can be returned to the seabed using a caisson for distribution of material evenly. For those cuttings that fail to meet the regulations for oil content they can be stored as waste and returned to shore for further processing. Alternatively, they may be re-injected into a disposal well which is then sealed. Key environmental aspects for cuttings will be:

- Discharges to sea of materials from the well.

The potential measures are listed below:

- Conventional treatment methods for removing OBMs from cuttings to required levels (e.g. under OSPAR) including shale shakers and hydrocyclones; and
- Emerging technologies such the Thermomechanical Cuttings Cleaner (TCC) which can clean contaminated cuttings to well below OSPAR required levels.

The risk levels for handling cuttings contaminated with oil based muds are presented in Table 6.8.

Table 6.8: Risk and impacts of handling cuttings contaminated with oil based muds

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (planned) damage to marine ecosystems	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation	3 low

Main Environmental Aspects	Impacts	Risk Level
	systems should also reduce the hazard of the released materials towards marine life. The further dilution[58] of these materials within sea water will continue to reduce the risk of impact.	
Discharges to sea (planned) damage to water quality	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM or the prohibition of harmful substances under Annex I of the Barcelona Convention[55]), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[59] of these materials within sea water will reduce concentrations affecting water quality.	3 low
Discharges to sea (planned) seabed fouling	The main impacts on seabed fouling is where solid material such as drilling muds and cuttings smothers the sea bed affecting the benthic species that live in the surface layers of the seabed. Effects can be significant killing all life in the surface layers. However on completion of the process the affected area is expected to recover quickly with re-population from surrounding areas.	6 moderate

6.3.6 Cementing of well casing

6.3.6.1 Overview

The drilling part of well development is carried out in phases; after completion of each phase a steel casing is inserted into the well and cemented into place to ensure the integrity of the well and to prevent any well material from being lost to the marine environment. This involves the pumping of cement down into the well bore, hardening and testing before the next phase of drilling is carried out. The environmental aspects at risk will be:

- Discharges of materials to sea; and
- Noise from pumping equipment – the measures to manage noise will be the same as 'seismic surveys' detailed in section 3.5.1. No further discussion of measures is given here.

6.3.6.2 Measures

Measures assumed to be in place include:

- Review and planning of cement required based on previous drilling operations; and
- Cement mixed at point of use to avoid excess quantities being pumped into the well-bore.

6.3.6.3 Issues

The risk levels for cementing of well casing are presented in Table 6.9

[58] Refer to section 1.4.3 on cumulative impacts.
[59] Refer to section 1.4.3 on cumulative impacts.

Table 6.9: Risk and impacts of cementing of well casing

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (planned) damage to marine ecosystems	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[60] of these materials within sea water will continue to reduce the risk of impact.	3 low
Discharges to sea (planned) damage to water quality	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM)limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[61] of these materials within sea water will reduce concentrations affecting water quality.	3 low
Discharges to sea (planned) seabed fouling	The risk management measures in place are intended to reduce the quantity of any material discharged to sea, however as this will likely be solid matter the potential for any discharged material to reach the seabed is greater. The main impact here would be from smothering the surface layers of seabed where benthic species exist. The likely impact would be moderate in the short term, but affected areas would be expected to recover quickly from benthic species repopulating affected area.	6 moderate
Underwater noise in the marine environment (potential to cause disturbance to marine life)	Underwater noise generated during the cementing phase relates to the 'humming' noise generated by pumping equipment and drill machinery. Noise generation from these sources will have less impact than piling and rock dumping during installation and significantly less impact than seismic surveys during life cycle stage 1.	2 low

6.3.7 **Well-bore clean up**

6.3.7.1 Overview

On completion of the well drilling, it is necessary to perform well-bore clean-up to remove any remaining drilling muds, cuttings and loose materials from the well-bore before production. This operation is completed by flushing the well out with water and 'clean-up pills' with any residual materials returned to the surface. Clean-up pills consist of solvents that breakdown residual drilling muds, followed by surfactants that increase the wettability of the well interior. The process will also require the use of flaring to manage any excess of gas produced. The environmental aspects likely to be affected by this process will be:

- Releases to air from flaring;
- Discharges to sea from drop out of flaring; and

[60] Refer to section 1.4.3 on cumulative impacts.
[61] Refer to section 1.4.3 on cumulative impacts.

- Discharges to sea from well leak – the measures to manage this issue are the same as those detailed under 'Drilling (with the use of water based muds and oil based muds)'. No further discussion of measures is detailed here.

6.3.7.2 Measures

Releases to air from flaring

- Best Available Technology (BAT) for use of flaring including maintenance and ensuring efficient running of the equipment in place;
- Planned and metered flaring to avoid excess flaring requirements; and
- Gas reinjection where technically feasible as an alternative to flaring (IOPG, 2000).

Discharges to sea from drop out of flaring

- Technical design, including apparatus to reduce water content likely to cause drop out, such as the use of 'knock-out' drums upstream of the flare to remove any liquid fraction (Ffyne, 2014 and Allied Flare, 2015); and
- Bird-watch – monitor the area around the flare where drop-out is likely to occur and ensure that no sea birds are in the vicinity likely to be effected (Peterhead, 2014).

6.3.7.3 Issues

The risk levels for well-bore clean-up are presented in Table 6.10.

Table 6.10: Risk and impacts of well-bore clean-up

Main Environmental Aspects	Impacts	Risk Level
Releases to air - flaring (local air quality)	Impact to local air quality would result from the flaring of gases potentially generating air quality pollutants such as NOx, SOx and VOCs. For gas flows the issue of particulate matter is probably less of an issue. These emissions will vary with the quantity of gas flared, but are judged as generally being relatively low.	4 low
Releases to air - flaring (contribution to international greenhouse gas emissions)	Combustion of fossil fuels will generate carbon dioxide and greenhouse gases. These emissions contribute to climate change and will vary with the quantity of gas flared, but is judged as generally being relatively low.	4 low
Discharges to sea (accidental) – flaring drop-out damage to marine ecosystems	OSPAR/HELCOM limits (see 2.4.2.3) on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[62] of these materials within sea water will continue to reduce the risk of impact.	3 low
Discharges to sea (accidental) – flaring drop-out damage to water quality	OSPAR/HELCOM limits (see 2.4.2.3) on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[63] of these materials within sea water will reduce concentrations affecting water quality.	3 low

[62] Refer to section 1.4.3 on cumulative impacts.
[63] Refer to section 1.4.3 on cumulative impacts.

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) – flaring drop-out seabed fouling	The gas generated during this phase will also contain a certain amount of condensate (light liquid hydrocarbon fraction). This has the potential to impact the marine environment. However measures such as 'knock out' drums can be used to reduce the amount of condensate in the gas flow before flaring.	6 moderate
Discharges to sea (accidental) – well leakage damage to marine ecosystems	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[64] of these materials within sea water will continue to reduce the risk of impact.	3 low
Discharges to sea (accidental) – well leakage damage to water quality	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[65] of these materials within sea water will reduce concentrations affecting water quality.	3 low
Discharges to sea (accidental) – well leakage seabed fouling	The process of wellbore clean-up is intended to remove any final cuttings, drilling muds or residues of chemicals used in drilling prior to production. The potential release of solid matter the potential for any discharged material to reach the seabed is greater. The main impact here would be from smothering the surface layers of seabed where benthic species exist. The likely impact would be moderate in the short term, but affected areas would be expected to recover quickly from benthic species repopulating affected area.	6 moderate

6.3.8 **Introduction of completion fluids**

6.3.8.1 Overview

Introduction of completion fluid is the final stage in preparing the well before production can be commenced. The use of completion fluid is intended to protect the well from attack by rusting processes as well as the build-up of microbial life within the well itself, which can also damage the integrity of the well. Completion fluids are therefore made up of chemical mixtures that will include additives (e.g. water soluble polymers) corrosion inhibitors, biocides and oxygen scavengers. This is so that it does not damage the permeability of the reservoir rock. Although compositions are not very well documented, typically, filtered brines are used, sometimes with polymers such as hydroxyl-ethylcellulose or polysaccharides[66].

[64] Refer to section 1.4.3 on cumulative impacts.
[65] Refer to section 1.4.3 on cumulative impacts.
[66] bookings.rscspecialitychemicals.org.uk/publications/CITOI%20IV.pdf

The key environmental aspect at risk from this process will be the loss of any completion fluids from the well into the marine environment. The selection of chemicals will follow the same processes as highlighted previously during the drilling phase particularly the selection of chemicals of lower hazard or risk. As the measures to control this risk will be the same as those stated within 'drilling (with the use of water based muds and oil based muds)' in section 6.3. No further comment is made here on measures.

6.3.8.2 Measures

See Measures detailed for discharges to sea under 'Drilling (with the use of water based muds and oil based muds)'.

6.3.8.3 Issues

The risk levels for introduction of completion fluids are presented in Table 6.11.

Table 6.11: Risk and impacts of introduction of completion fluids

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) damage to marine ecosystems	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[67] of these materials within sea water will continue to reduce the risk of impact.	3 low
Discharges to sea (accidental) damage to water quality	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[68] of these materials within sea water will reduce concentrations affecting water quality.	3 low
Discharges to sea (accidental) seabed fouling	The main impacts on seabed fouling is where solid material such as residual drilling muds and cuttings smothers the sea bed affecting the benthic species that live in the surface layers of the seabed. These materials can be released as a result of completion fluids dislodging any remaining material in the well. Effects can be significant killing all life in the surface layers. However on completion of the process the affected area is expected to recover quickly with re-population from surrounding areas. Sensitive biota such as sponge or cold water coral communities are expected to take additional time to recover from accidental seabed fouling compared to other biota. However, the damage to these species caused by small quantities of accidentally discharged drill cuttings and/or muds will not be as severe as that caused by positioning apparatus on the seabed.	3 low

[67] Refer to section 1.4.3 on cumulative impacts.
[68] Refer to section 1.4.3 on cumulative impacts.

6.4 Stage 3 Production

6.4.1 Summary of environmental risks

The completion of lifecycle stage 2 will finalise the development of the well and commencement of production. Stage 3 will cover all topside activities to manage the flow and processing of the oil and gas produced, along with export via shipping vessel or pipeline. The topside activities will also require a wide range of systems to manage the more generic aspects such as power generation, waste management and cooling systems. The following key sub-stage processes and technologies within the production phase of the lifecycle will include:

7. Platform installation:
   - 7.1 Engineering, Procurement, and Construction (EPC);
   - 7.2 Transport of the platform;
   - 7.3 Piling for jacket;
   - 7.4 Rock dumping;
   - 7.5 Pre-commissioning; and
   - 7.6 Installation of seabed production infrastructure.
8. Platform operations:
   - 8.1 Chemical injection;
   - 8.2 Subsea production systems;
   - 8.3 Oil production, processing and handling;
   - 8.4 Gas production, processing and handling;
   - 8.5 Produced water management;
   - 8.6 Produced sand management;
   - 8.7 Off-gas management;
   - 8.8 Power generation and combustion equipment;
   - 8.9 Hydrocarbon and chemical storage;
   - 8.10 Diesel/chemical deliveries;
   - 8.11 Open loop seawater cooling;
   - 8.12 Heat, ventilation and air conditioning (HVAC);
   - 8.13 Topside drainage;
   - 8.14 Waste management;
   - 8.15 Oil off-take by vessel;
   - 8.16 Oil off-take by pipeline
   - 8.17 Gas export pipeline/tie-in equipment;
   - 8.18 Enhanced recovery (water flooding);
   - 8.19 Enhanced recovery (miscible gas injection); and
   - 8.20 Well stimulation (low volume hydraulic fracturing).

A summary of risk characteristics for Stage 3 production are outlined in Table 6.12 Further details of the risk assessment can be found in Appendix B.

Table 6.12: Production

Processes/ technologies	Environmental Aspect	Risk Characterisation (with expected management measures in place)			Risk Characterisation (without expected management measures in place)		
		Likelihood	Consequence	Risk	Likelihood	Consequence	Risk
7. Platform installation – floating, fixed							
7.1 Engineering, Procurement, and Construction (EPC) -	This phase involves the planning, logistics and management of the construction of the production installation. Depending on the type of installation (FPSO, steel jacket, gravity based platform, spar or subsea templates etc.) this may also include onshore construction processes. All EPC activities occur outside of the scope of the project.						
7.2 Transportation of platform to field	• Releases to air (local air quality impacts)	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Releases to air (emissions of greenhouse gas)	Highly Likely	Slight	5 moderate	Highly Likely	Slight	5 moderate
7.3 Piling for jacket foundations and/or mooring line anchors	• Seabed disturbance – placing of the platform on seabed[69]	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Underwater noise in the marine environment (disturbance to animals)	Likely	Slight	4 low	Highly likely	Slight	5 moderate
	• Releases to air (local air quality impacts)	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Releases to air (emissions of greenhouse gas)	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Discharges to sea – (accidental) – loss of hydraulic fluids during piling, damage to marine ecosystems[69]	Occasional	Slight	3 low	Occasional	Minor	6 moderate

[69] In deep waters and rough seas piling operations may be more inaccurate and margins for error lower, resulting in the potential for higher seabed disturbance and a greater risk of accidental fluid discharge.

	• Discharges to sea – (accidental) – loss of hydraulic fluids during piling, damage to water quality[69]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – (accidental) – loss of hydraulic fluids during piling, fouling seabed[69]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Visual impact – lighting from rig attracts birds and causes 'birdstrike'	Highly Likely	Slight	5 moderate	Highly likely	Minor	10 high
7.4 Rock dumping	• Seabed disturbance – use of rock dumping to secure platform[70]	Occasional	Moderate	9 high	Occasional	Moderate	9 high
7.5 Pre-commissioning (Hydrostatic testing / leak testing and water injection)	• Discharges to sea – (accidental) – loss of test fluids during finalisation of systems, damage to marine ecosystems	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – (accidental) – loss of test fluids during finalisation of systems, damage to water quality[71]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – (accidental) – loss of test fluids during finalisation of systems, fouling seabed[71]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high

[70] In deeper waters and rougher seas, rock dumping may be more inaccurate, resulting in a greater seabed disturbance.
[71] In rough seas and high winds, the risk of test fluids loss may increase as equipment is under stress and there are lower margins for operator error.

7.6 Installation of sea-bed production infrastructure Includes Electrical Submersible Pumps (ESPs), hydraulically-powered pumps, Pipeline End Terminations (PLETS), Riser Emergency Shutdown Valves (ESDVs), pigging equipment, manifolds, X-trees, etc. Also includes in-field flowlines, injection lines and umbilical.	• Seabed disturbance – establishing equipment on seabed[72]	Likely	Moderate	12 high	Likely	Moderate	12 high
	• Underwater noise in the marine environment (disturbance to animals)	Likely	Slight	4 low	Highly likely	Slight	5 moderate
8. Platform operations							
8.1Chemical injection	• Discharges to sea (accidental) - marine biodiversity/ habitat loss[73]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) - coastal biodiversity/ habitat loss[73]	Rare	Minor	4 low	Rare	Moderate	6 moderate

[72] In rough seas and deeper waters establishing equipment on the seabed may be more inaccurate, therefore this may potential result in increased seabed disturbance.
[73] In rough seas and deeper waters the risk of accidental discharges to sea may increase as equipment is under greater pressure and there are lower margins for operator error.

	• Discharges to sea (accidental) - deterioration in water quality	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) - sediment fouling/benthic habitat smothering[73]	Rare	Slight	2 low	Rare	Minor	4 low
8.2 Subsea production system Includes ESPs, hydraulically-powered pumps, FLETS, PLETS, ESDVs, pigging equipment, manifolds, X-trees, etc. Also includes in-field flowlines, injection lines and umbilicals	• Discharges to sea – (accidental) – loss of fluids during use of subsea equipment, damage to marine ecosystems[74]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – (accidental) – loss of fluids during use of subsea equipment, damage to water quality[74]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea – (accidental) – loss of fluids during use of subsea equipment, fouling seabed[74]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Underwater noise in the marine environment (disturbance to animals)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Physical presence – change of seabed structure	Highly Likely	Minor	10 high	Highly Likely	Minor	10 high
8.3 Oil production, processing and handling	• Discharges to sea (accidental) – Tier III* – Major incident – damage to marine environment	Rare	Major	8 moderate	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to coastal environment	Rare	Catastrophic	10 high	Likely	Catastrophic	20 very high

[74] For all accidental discharges to sea from subsea production systems, the risks may be greater in deeper and rougher waters, as there is greater pressure on the equipment.

	• Discharges to sea (accidental) – Tier III* – Major incident – damage to water quality	Rare	Moderate	6 moderate	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – fouling seabed marine environment	Rare	Moderate	6 moderate	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier II * – Moderate incident – damage to marine environment	Rare	Moderate	6 moderate	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – damage to coastal environment	Rare	Major	8 moderate	Occasional	Catastrophic	15 very high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – damage to water quality	Rare	Minor	4 low	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier II* – Moderate incident – fouling seabed marine environment	Rare	Minor	4 low	Occasional	Moderate	9 moderate
	• Discharges to sea (accidental) – Tier I* – Minor incident – damage to marine environment	Extremely rare	Minor	2 low	Occasional	Moderate	9 moderate
	• Discharges to sea (accidental) – Tier I* – Minor incident – damage to coastal environment	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea (accidental) – Tier I* – Moderate incident – damage to water quality	Extremely rare	Slight	1 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) – Tier I* – Minor incident – fouling seabed marine environment	Rare	Slight	2 low	Rare	Minor	4 low

8.4 Gas production, processing and handling	• Releases to air – (accidental) – loss of containment / leaking equipment release to atmosphere[75]	Occasional	Minor	6 moderate	Likely	Minor	8 moderate
	• Releases to air – (accidental) – unplanned need to vent or flare gas during production[75]	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air – (planned) – planned venting or flaring as per permit	Occasional	Moderate	9 high	Likely	Moderate	12 high
8.5 Produced water management	• Discharges to sea (accidental) Marine biodiversity/ habitat loss[76]	Occasional	Minor	6 moderate	Highly likely	Minor	10 high
	• Discharges to sea (accidental) Coastal biodiversity/ habitat loss[76]	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea (accidental) Deterioration in water quality[76]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea (accidental) Sediment fouling/benthic habitat smothering[76]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea (planned – after onsite treatment) Marine biodiversity/ habitat loss	Highly Likely	Slight	5 moderate	Likely	Minor	8 moderate
	• Discharges to sea (planned – after onsite treatment) Coastal biodiversity/ habitat loss	Rare	Slight	2 low	Occasional	Slight	3 low
	• Discharges to sea (planned –	Rare	Slight	2 low	Occasional	Slight	3 low

[75] In high winds, low temperatures and rougher seas there is greater stress on containment equipment, therefore containment failure of produced gas may be more likely.
[76] In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of untreated produced water may be more likely.

	after onsite treatment) Deterioration in water quality						
	• Discharges to sea (planned – after onsite treatment) Sediment fouling/benthic habitat smothering	Rare	Slight	2 low	Occasional	Slight	3 low
8.6 Produced sand management	• Discharges to sea (accidental) Marine biodiversity/ habitat loss[77]	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Discharges to sea (accidental) Deterioration in water quality[77]	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Discharges to sea (accidental) Sediment fouling/benthic habitat smothering[77]	Occasional	Minor	6 moderate	Occasional	Minor	6 moderate
	• Discharges to sea (planned – after onsite treatment) Marine biodiversity/ habitat loss	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Discharges to sea (planned –- after onsite treatment) Deterioration in water quality	Occasional	Slight	3 low	Occasional	Slight	3 low
	• Discharges to sea (planned –- after onsite treatment) Sediment fouling/benthic habitat smothering	Occasional	Minor	6 moderate	Occasional	Minor	6 moderate
8.7 Off-gas management - flaring	• Releases to air (accidental) (local air quality impacts)	Occasional	Slight	3 low	Likely	Minor	8 moderate
	• Releases to air (accidental) (emission of greenhouse gas)	Occasional	Minor	6 moderate	Occasional	Moderate	9 moderate
	• Releases to air (planned)	Likely	Slight	4 low	Likely	Minor	8 moderate

[77] In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of untreated produced sand may be more likely.

	(local air quality impacts)						
	• Releases to air (planned) (emission of greenhouse gas)	Likely	Moderate	12 high	Likely	Major	16 very high
8.8 Power generation and combustion equipment	• Releases to air – main power generation units (local air quality impacts)	Rare	Slight	2 low	Rare	Minor	4 low
	• Releases to air – main power generation units (contribution to global emissions for greenhouse gas)	Likely	Slight	4 low	Highly Likely	Slight	5 moderate
	• Releases to air – auxiliary equipment excluding main power generation (local air quality impacts)	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Releases to air auxiliary equipment excluding main power generation (contribution to global emissions for greenhouse gas)	Occasional	Slight	3 low	Occasional	Minor	6 moderate
8. 9 Hydrocarbon and chemical storage	• Discharges to sea (accidental) – Tier III* – Major incident – damage to marine environment	Extremely Rare	Major	4 low	Rare	Catastrophic	10 high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to coastal environment	Extremely Rare	Catastrophic	5 moderate	Rare	Catastrophic	10 high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to water quality	Extremely Rare	Major	4 low	Rare	Catastrophic	10 high
	• Discharges to sea (accidental) – Tier III* – Major incident – fouling seabed marine environment	Extremely Rare	Major	4 low	Rare	Major	8 moderate
	• Discharges to sea (accidental) –	Rare	Moderate	4 low	Rare	Major	8 moderate

	Tier II* – Major incident – damage to marine environment						
	• Discharges to sea (accidental) – Tier II* – Major incident – damage to coastal environment	Rare	Moderate	4 low	Rare	Major	8 moderate
	• Discharges to sea (accidental) – Tier II* – Major incident – damage to water quality	Rare	Moderate	4 low	Rare	Major	8 moderate
	• Discharges to sea (accidental) – Tier II* – Major incident – fouling seabed marine environment	Rare	Moderate	4 low	Rare	Major	8 moderate
8.10 Diesel/chemical deliveries/loading	• Discharges to sea (accidental) – Tier I* – Major incident – damage to marine environment	Rare	Moderate	6 moderate	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier I* – Major incident – damage to coastal environment	Rare	Major	8 moderate	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier I* – Major incident – damage to water quality	Rare	Minor	4 low	Occasional	Major	12 high
	• Discharges to sea (accidental) – Tier I* – Major incident – fouling seabed marine environment	Rare	Minor	4 low	Occasional	Moderate	9 high
8.11 Open loop seawater cooling of process and utility systems	• Discharges to sea (planned) – Thermal affects - Marine biodiversity/ habitat loss	Likely	Slight	4 low	Likely	Slight	4 low
	• Discharges to sea (accidental) – residual antifoulant - Marine	Likely	Slight	4 low	Likely	Slight	4 low

	biodiversity/ habitat loss[78]						
8.12 Heating, Ventilation, and Air Conditioning (HVAC) systems	• Releases to air (accidental) – leaking air conditioning equipment[78]	Likely	Slight	4 low	Likely	Minor	8 moderate
8.13 Topside drainage systems	• Discharges to sea (accidental) – Tier I* – Minor incident – damage to marine environment	Likely	Minor	8 moderate	Likely	Moderate	12 high
	• Discharges to sea (accidental) – Tier I* – Minor incident – damage to coastal environment	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea (accidental) – Tier I* – Moderate incident – damage to water quality	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) – Tier I* – Minor incident – fouling seabed marine environment	Rare	Slight	2 low	Rare	Minor	4 low
8.14 Waste management	• Discharges to sea (accidental) – Liquid wastes - Marine biodiversity/ habitat loss[79]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea (accidental) – Liquid wastes - Deterioration in water quality[79]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea (accidental) – Liquid wastes - Sediment fouling/benthic habitat smothering[79]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea (accidental) –	Occasional	Minor	6 moderate	Occasional	Minor	6 moderate

[78] In high winds, low temperatures and rough seas there is greater stress on equipment, therefore accidental discharges of residual anti-foulant or HVAC fluids may be more likely.

[79] In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of waste may be more likely.

	solid waste - Marine biodiversity/ habitat loss[79]						
	• Discharges to sea (accidental) – solid waste - Sediment fouling/benthic habitat smothering[79]	Occasional	Minor	6 moderate	Occasional	Minor	6 moderate
8.15 Oil offtake – vessel	• Discharges to sea (accidental) – Tier III* – Major incident – damage to marine environment	Extremely Rare	Major	4 low	Occasional	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to coastal environment	Extremely Rare	Catastrophic	5 moderate	Occasional	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to water quality	Extremely Rare	Moderate	3 low	Occasional	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – fouling seabed marine environment	Extremely Rare	Moderate	3 low	Occasional	Major	12 high
8.16 Oil export pipeline/tie in equipment	• Discharges to sea (accidental) – Tier III* – Major incident – damage to marine environment	Rare	Major	8 moderate	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to coastal environment	Rare	Catastrophic	10 high	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – damage to water quality	Rare	Moderate	6 moderate	Likely	Catastrophic	20 very high
	• Discharges to sea (accidental) – Tier III* – Major incident – fouling seabed marine environment	Rare	Moderate	6 moderate	Occasional	Major	12 high
8.17 Gas export pipeline/tie in	• Releases to air (accidental) – containment failure in pipeline	Rare	Minor	4 low	Occasional	Minor	6 moderate

equipment	(contribution to global emissions for greenhouse gas)[80]						
8.18 Water flooding	• Discharges to sea of additional produced water (accidental) Marine biodiversity/ habitat loss[81]	Occasional	Minor	6 moderate	Highly likely	Minor	8 moderate
	• Discharges to sea of additional produced water (accidental) Coastal biodiversity/ habitat loss[81]	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea of additional produced water (accidental) Deterioration in water quality[81]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea of additional produced water (accidental) Sediment fouling/benthic habitat smothering[81]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea of additional produced water (planned – after onsite treatment) Marine biodiversity/ habitat loss	Highly Likely	Slight	5 moderate	Likely	Minor	8 moderate
	• Discharges to sea of additional produced water (planned – after onsite treatment) Coastal biodiversity/ habitat loss	Rare	Slight	2 low	Occasional	Slight	3 low
	• Discharges to sea of additional produced water (planned – after onsite treatment)	Rare	Slight	2 low	Occasional	Slight	3 low

[80] In deeper waters greater lengths of pipeline are exposed and pressures are greater, therefore there may be an increased change of a pipeline containment failure.
[81] In rougher seas and high winds, the risk of an accidental discharge of additional produced water, produced as a result of waterflooding, may be greater as equipment is under greater stress and margins of error are lower.

	Deterioration in water quality						
	• Discharges to sea of additional produced water (planned – after onsite treatment) Sediment fouling/benthic habitat smothering	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air (local) – injection equipment	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (global) – injection equipment	Minor	Rare	3 low	Minor	Rare	3 low
	• Underwater noise in the marine environment resulting from induced seismicity • (disturbance to animals)	Rare	Slight	2 low	Occasional	Slight	3 low
8.19 Enhanced recovery (miscible gas injection)	• Releases to air (local) – injection equipment	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (global) – injection equipment	Minor	Rare	3 low	Minor	Rare	3 low
	• Underwater noise in the marine environment resulting from induced seismicity (disturbance to animals)	Rare	Slight	2 low	Occasional	Slight	3 low
8.20 Well stimulation (low volume hydraulic fracturing)	• Discharges to sea of flowback (accidental) Marine biodiversity/ habitat loss[82]	Occasional	Minor	6 moderate	Highly likely	Minor	8 moderate
	• Discharges to sea of flowback (accidental) Coastal biodiversity/ habitat loss[82]	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea of flowback	Rare	Slight	2 low	Rare	Minor	4 low

[82] In rougher seas and high winds, the risk of an accidental discharge of fracturing fluid flowback may be greater as equipment is under greater stress and margins of error are lower.

	(accidental) Deterioration in water quality[82]						
	• Discharges to sea (accidental) Sediment fouling/benthic habitat smothering[82]	Rare	Slight	2 low	Rare	Minor	4 low
	• Discharges to sea of flowback (planned – after onsite treatment) Marine biodiversity/ habitat loss	Likely	Slight	5 moderate	Likely	Minor	8 moderate
	• Discharges to sea of flowback (planned – after onsite treatment) Coastal biodiversity/ habitat loss	Rare	Slight	2 low	Occasional	Slight	3 low
	• Discharges to sea of flowback (planned – after onsite treatment) Deterioration in water quality	Rare	Slight	2 low	Occasional	Slight	3 low
	• Discharges to sea of flowback (planned – after onsite treatment) Sediment fouling/benthic habitat smothering	Rare	Slight	2 low	Occasional	Slight	3 low
	• Discharges to sea (accidental) – Tier I* – Minor incident – impacts to marine environment	Likely	Minor	8 moderate	Likely	Moderate	12 high
	• Discharges to sea (accidental) – Tier I* – Minor incident – impacts to coastal environment	Rare	Minor	4 low	Rare	Minor	4 low
	• Discharges to sea (accidental) – Tier I* – Moderate incident – impacts to water quality	Occasional	Slight	3 low	Occasional	Minor	6 moderate
	• Discharges to sea (accidental) –	Rare	Slight	2 low	Rare	Minor	4 low

	Tier I* – Minor incident – fouling seabed						
	• Releases to air (local) – injection equipment	Slight	Occasional	4 low	Minor	Occasional	6 moderate
	• Releases to air (global) – injection equipment	Minor	Rare	3 low	Minor	Rare	3 low
	• Underwater noise in the marine environment resulting from induced seismicity (disturbance to animals)	Rare	Slight	2 low	Occasional	Slight	3 low

*Explanation of the IPIECA tiered scheme for accidents is provided in section 6.3 under Drilling (with the use of water based muds and oil based muds). For all of these aspects, the likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error during production.

Table 6.13 provides a list of processes and technologies assessed to have possible impact in stage 3. In a number of cases the nature and level of the risk identified mirrors similar processes already discussed in stage 2 of the life-cycle. In these cases the measures that are used to the control the risk will also be the same. To avoid duplication, Table 6.13 provides details of where further discussion can be found in earlier sections and details the remaining processes within this part of the report.

Table 6.13: Production processes and technologies within life-cycle stage 3 (production) that may have potential risks and impacts

No.	Processes description	Detailed here	Environmental Aspect	If not detailed in this section, discussion can be found under section number and title:
7.1	EPC and planning – onshore phase outside of the scope of the current project			
7.2	Transport of platform to site		Releases to air	6.2 'Marine Transport'
7.3	Piling for jacket foundations and/or mooring line anchors		Seabed disturbance, Noise, and discharges to sea	6.3 'Positioning of the drilling rig on the seabed' and
			Releases to air	6.3 'Drilling (with use of water based muds and oil and based muds)
		√	Lighting and visual impacts	
7.4	Rock dumping		Seabed disturbance	6.3. 'Positioning of the drilling rig on the seabed'
7.5	Pre-commissioning (Hydrostatic testing / leak testing and water injection	√	Discharges to sea	
7.6	Installation of equipment to seabed for integrated networks		Seabed disturbance	6.3. 'Positioning of the drilling rig on the seabed'
8.1	Chemical injection		Discharges to sea	6.3 'Induction of completion fluids' and 'Drilling (with use of water based muds and oil and based muds)
8.2	Subsea production system Includes ESPs, hydraulically-powered pumps, FLETS, PLETS, ESDVs, pigging equipment, manifolds, X-trees, etc. Also includes in-field flowlines, injection lines and umbilicals		Discharge to sea	6.3. 'Drilling (with use of water based muds and oil and based muds)

No.	Processes description	Detailed here	Environmental Aspect	If not detailed in this section, discussion can be found under section number and title:
8.3	Oil production, processing and handling		Accidental events Tier I, II, and III,	6.3. 'Drilling (with use of water based muds and oil and based muds)
8.4	Gas production, processing and handling	√	Releases to air	
8.5	Produced water management	√	Discharges to sea	
8.6	Produced sand management	√	Discharges to sea	
8.7	Off-gas management – Flaring		Releases to air	6.3. 'Well bore clean-up'
8.8	Power generation and combustion equipment		Releases to air	6.3 'Drilling (with use of water based muds and oil and based muds)
8.9	Hydrocarbon and chemical storage	√	Accidental events Tier III	
8.10	Diesel/chemical deliveries/loading	√	Accidental events Tier I - Discharges to sea	
8.11	Open loop seawater cooling of process and utility systems	√	Discharges to sea	
8.12	Heating, Ventilation, and Air Conditioning (HVAC) systems	√	Releases to air	
8.13	Topside drainage systems	√	Discharges to sea	
8.14	Waste management	√	Discharges to sea	
8.15	Oil offtake – vessel	√	Accidental Events Tier III	
8.16	Oil export pipeline/tie in equipment	√	Accidental Events Tier III	
8.17	Gas export pipeline/tie in equipment	√	Releases to air	
8.18	Water flooding		Discharges to sea	See 3.4.3 produced water management
		√	Releases to air – injection and filtration equipment	

No.	Processes description	Detailed here	Environmental Aspect	If not detailed in this section, discussion can be found under section number and title:
8.19	Enhanced recovery (miscible gas injection)	√	Releases to air – injection equipment	
8.20	Well stimulation (low volume HF)	√	Discharges to sea - flowback	
		√	Releases to air – injection equipment	
			Discharges to sea – chemicals	See 3.4.3 hydrocarbon and chemical storage – Tier I incident only due to low volumes
			Underwater noise – disturbance to animals resulting from induced seismicity	See 3.4.1. underwater noise related to drilling

6.4.2 Piling for jacket foundations and/or mooring line anchors

6.4.2.1 Overview

The majority of the issues related to the positioning and establishment of the oil rig installation have been covered elsewhere in this document (see Table 6.), however one outstanding issue relates to the impacts caused by the presence of the installation itself. In particular the impact upon birds from the lighting used on the installation which results in 'bird strike', and potentially could have a significant impact on migratory birds.

6.4.2.2 Measures

The measures assumed to be in place are listed below chronologically to match the order of the environmental aspects identified above:

- Visual impact;
- Loss of fishing areas – "Consent to locate" permits required for placing of an offshore installation. This will include stakeholder notifications (e.g. coastguard, fishing representative bodies) regarding location of rigs and pipelines and opportunity to ensure that all needs are met; and
- Lighting:
    a. Use of lights at UV wavelengths which are less likely to attract birds and create bird-strike;
    b. Use of strobing lights to avoid attracting birds;
    c. Use of additional shielding on lights to avoid attracting birds; and
    d. Selective use of lights so only used when necessary.

Table 6.14: Risk and impacts of piling for jacket foundations and/or mooring line anchors

Main Environmental Aspects	Impacts	Risk Level
Visual impact – lighting from rig attracts birds and causes 'birdstrike'	The OSPAR (2012a) review into the effects of oil rig lighting on bird-strike in the North Sea area highlights a key issue in that the majority of birds affected are not sea birds, but migrating garden birds. The reports state that 75% of the birds killed come from the thrush family. This suggested that the potential consequence for the garden bird populations (particularly thrush) could be particularly serious. Moreover the issue of bird-strike within the offshore oil and gas sector is likely to be an area where measures to avoid bird-strike are less fully adopted.	5 moderate
Visual impact – Lost fishing areas increases burden elsewhere	The placement of oil rig equipment at sea and necessary use of exclusion zones to avoid collision with oil rig platforms means that fishing vessels are no longer able to trawl in these specific areas. The loss fishing areas and relocating of fishing vessels potentially increases burden elsewhere. In practice the competing needs of space and resources are managed through permitting and regulatory control such as 'consent to locate'. Overall risk ranking is judged as generally moderate due to likely frequency of issues arising and potential impact which is expected to be relatively minor.	5 moderate

6.4.3 Pre-commissioning

6.4.3.1 Overview

Pre-commissioning includes all remaining activities to prepare the site for production, including preparation of topside systems and final checks within the well. The principal risk for this process will be the use of hydrostatic leak testing to check the final integrity of the well for any leaks before production can commence. Hydrostatic leak testing involves applying pressure to the well using air and/or a mixture of gases such as nitrogen or helium and then assessing the entire system for leaks (Maxbar, 2015). Because the gases used are all natural substances found in the atmosphere the leaking gas itself is not an issue, but where leaks are found it is possible that quantities of other substances in the well such as completion fluids and hydrocarbons could be discharged to the marine environment.

The environmental aspect at risk during this process is therefore discharges to sea. The nature of the materials that could be released will match those from earlier processes in life-cycle stage 2, particularly those during drilling and injection of completion fluids. The measures in place to mitigate this risk will be the same as those discussed under 'drilling (with the use of water based muds and oil based muds)'. No further comment is made here on measures.

6.4.3.2 Measures

See Measures detailed for discharges to sea under 'Drilling (with the use of water based muds and oil based muds)'.

6.4.3.3 Issues

The risk levels for pre-commissioning are presented in Table 6.15.

Table 6.15: Risks and impacts of pre-commissioning

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) – hydrostatic leak testing damage to marine ecosystems	The use of limits on hydrocarbon content of released materials and separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[83] of these materials within sea water will continue to reduce the risk of impact in the short term.	3 low
Discharges to sea (accidental) – hydrostatic leak testing damage to water quality	The use of the measures identified including use of limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials into sea-water. The further dilution[84] of these materials within sea water will reduce concentrations affecting water quality.	3 low
Discharges to sea (accidental) – hydrostatic leak testing seabed fouling	The main impacts on seabed fouling is where solid material such as drilling muds and cuttings smothers the sea bed affecting the benthic species that live in the surface layers of the seabed. These materials can be released as a result of pressure testing dislodging any remaining material in the well. Effects can be significant killing all life in the surface layers. However on completion of the process the affected area is expected to recover quickly with re-population from surrounding areas.	6 moderate

[83] Refer to section 1.4.3 on cumulative impacts.
[84] Refer to section 1.4.3 on cumulative impacts.

6.4.4 Processing of gas produced

6.4.4.1 Overview

Oil and gas produced from the well will typically be managed using the same processes involving separation tanks; for gas only operations the key aspect of processing the gas produced will involve de-watering exercises potentially with the use of desiccants to remove moisture from the gas flow. Containment of gas produced from the well will be a key management issues both for the safety of workers on the installation and also for releases to air. The environmental aspect in this process will be the loss of gas to air from containment leaks during the processing phase.

6.4.4.2 Measures

Measures assumed to be in place include:

- Elimination of flanged connections to as far an extent as practicable;
- Leak detection and repair programmes; and
- Valve and flange specifications.

6.4.4.3 Issues

The risk levels for processing of gas produced are presented in Table 6.16.

Table 6.16: Risks and impacts of processing of gas production

Main Environmental Aspects	Impacts	Risk Level
Releases to air – (accidental) – loss of containment	The release of hydrocarbons to air which includes both air quality pollutants and greenhouse gases will have impacts for local air quality as well as contribution to greenhouse gas emissions.	6 moderate
Releases to air – (accidental) – unplanned need to vent or flare gas during production	Venting or combustion of fossil fuels will generate carbon dioxide and greenhouse gases. These emissions contribute to climate change However the management of gases on the installation is generally tightly controlled and managed. The likely frequency of needing to vent or flare within unplanned conditions should be rare. Due to the expected low frequency of this activity the overall risk rating is judged as generally low.	2 low
Releases to air – (planned) – planned venting or flaring as per permit	Venting or combustion of fossil fuels will generate carbon dioxide and greenhouse gases. These emissions contribute to climate change. Management of gas flows on the installation are generally tightly controlled with planned flaring controlled by permit. However the quantity of gas flared and frequency in needing to flare or vent means the risk rating for this set of impacts is rated as relatively high.	9 high

6.4.5 Produced water management

6.4.5.1 Overview

Production from the well will generate a mixture of water, oil and gas which requires separation into component parts for further management and export. A series of separation tanks are used to carry-out this process; however the produced water component will likely still contain levels of hydrocarbon contamination which prevents its safe return to sea. Use of hydrocyclone equipment can be used to further extract hydrocarbon fractions from produced water. The key environmental aspects affected by this process are:

- Planned discharges to sea of treated produced water which should meet the requirements of OSPAR, HELCOM, the Barcelona Convention (noting that these requirements vary) and Marpol; and
- Unplanned discharges to sea which occur due to loss of containment while processing.

6.4.5.2 Measures

Measures assumed to be in place include:

- Use of hydrocyclones to remove hydrocarbon content within produced water and return hydrocarbon fraction to upstream processing;
- Sampling and analysis of hydrocarbon contaminated water to ensure, hydrocarbon content is below a defined threshold (e.g. 40 mg/l under the Barcelona Convention, 30 mg/l under OSPAR and 15 mg/l (in most cases) under HELCOM);
- Environmental Statement with identification of risks and oil spill modelling specific to the site;
- Maintenance and system checks of containment systems used for processing;
- Reinjection systems to use produced water for water flooding to increase hydrocarbon yield (Mariner, 2012); and
- Oil and water separation systems to reduce hydrocarbon content.

6.4.5.3 Issues

The risk levels for processing of produced water are presented in Table 6.17.

Table 6.17: Risks and impacts of processing produced water

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) Marine biodiversity	Impacts from the accidental discharge of produced water on marine environments assumes that the water produced has not been fully treated and will exceed the safe limits set under OSPAR, HELCOM or the Barcelona Convention (noting that these limits vary). Dependent on the quantity of produced water discharged to sea, the impacts could be more significant. Assuming this is the case the overall risk rating for this risk is judged to be generally moderate.	6 moderate
Discharges to sea (accidental) Coastal biodiversity	The impact detailed from this risk involves the discharged material to sea reaching coastal environments and then causing impact for coastal species both within the marine environment and to avian and terrestrial species in the near-shore. Based on the measures in place the potential to cause impact is considered minor based on the risk matrix, and likely occurrence of coastal impacts would be rare.	4 low
Discharges to sea (accidental) Deterioration in water quality	The main issue with accidental loss of produced water will be that it is still contaminated by hydrocarbons. The use of separation tanks will greatly reduce hydrocarbon concentration but use of technologies such as hydrocyclones are needed to reduce hydrocarbon content below the safe thresholds set by OSPAR, HELCOM or the Barcelona Convention (noting that these limits vary). Direct impacts on water quality as a result of accidentally discharged produced water are expected to be short lived as oil readily degrades in the marine environment.	2 low

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) Sediment fouling	The main issue with accidental loss of produced water will be that it is still contaminated by hydrocarbons. This material will likely remain on the sea surface and form emulsion, with the risk of then sinking down to the sea bed.	2 low
Discharges to sea (planned) Marine biodiversity	The measures detailed are intended to reduce the hydrocarbon content below the safe limits set out by OSPAR, HELCOM or the Barcelona Convention. However full removal of quantities of hydrocarbons is difficult and costly to achieve. Planned release of produced water will still contain trace quantities of hydrocarbons which have the potential to negatively affect marine populations. Risk rating is still moderate, but ranked score is higher for accidental release than for planned releases.	5 moderate
Discharges to sea (planned) Coastal biodiversity	The impact detailed from this risk involves the material discharged to sea reaching coastal environments and then causing impact for coastal species both within the marine environment but avian and terrestrial species in the near-shore. Based on the measures in place the potential to cause impact is considered minor based on the risk matrix, and likely occurrence of coastal impacts would be rare.	2 low
Discharges to sea (planned) Deterioration in water quality	The use of the measures detailed will reduce the hydrocarbon content of produced water below the threshold set by OSPAR, HELCOM or the Barcelona Convention. Direct impacts on water quality as a result of planned discharged produced water are expected to be limited and short lived due to low concentrations and the fact that oil readily degrades when in low concentrations in the marine environment.	2 low

6.4.6 Produced sand management

6.4.6.1 Overview

Depending on the geology at the well, the generation of sand during production will vary in the quantity produced. An environmental statement by Mariner (2012), has recognised that sand generation can create a problem blocking filters or safety valve systems which then have to be manually cleaned. The options for managing sand are two-fold: those measures used 'down well' to minimise or prevent the creation of sand within produced materials; then latterly where sand has been produced measures to dewater and remove hydrocarbon fractions so that sand can be returned to sea. The environmental aspects are:

- Discharges to sea (both planned and unplanned) which affect the marine species and water quality; and
- Discharges to sea which cause sea bed disturbance, particularly smothering of benthic species. The risk for this aspect may be more serious for planned discharges as the quantities involved may be greater.

6.4.6.2 Measures

Measures assumed to be applied include:

- Modelling of geology at planning stage to predict likely issues with sand generation during production (Schlumberger, 2004);
- Use of 'open hole' gravel packs to minimise sand generation (Mariner, 2012);

- In well filtration systems such as 'slotted liners with screens' to reduce sand generated;
- Sampling and analysis of hydrocarbon contaminated water to ensure hydrocarbon content is below 30 mg/l (OSPAR, 2014) or equivalent thresholds under HELCOM (15 mg/l in most cases) or the Barcelona Convention (40 mg/l); and
- Use of caisson below the sea surface to more evenly distribute returned sand.

6.4.6.3 Issues

The risk levels for processing of produced sand management are presented in Table 6.18.

Table 6.18: Risk and impacts of produced sand management

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) Marine biodiversity	Produced sand will be treated to remove hydrocarbon content as far as possible. Return of produced sand to sea will make use of a sub-sea caisson to avoid impact from suspended sand increasing turbidity and blocking sunlight to surface layers. The impact on marine species is likely to be limited.	3 low
Discharges to sea (accidental) Deterioration in water quality	The introduction of produced sand back to sea which increases the quantity of suspended sediment within the water column can impact water quality. However these effects would be expected to be short lived with sediment quickly settling out of the water column.	3 low
Discharges to sea (accidental) Sediment fouling	The main impact from return of produced sand to sea will be the smothering of the seabed which negatively affects benthic species. The quantity of sand generated and lost during an accidental release is less clear. However the dispersion of sand across a wider area will limit the impact with seabed species expected to recover quickly	6 moderate
Discharges to sea (planned) Marine biodiversity	Produced sand will be treated to remove hydrocarbon content as far as possible. Return of produced sand to sea will make use of a sub-sea caisson to avoid impact from suspended sand increasing turbidity and blocking sunlight to surface layers. The impact on marine species is likely to be limited.	3 low
Discharges to sea (planned) Deterioration in water quality	The introduction of produced sand back to sea which increases the quantity of suspended sediment within the water column can impact water quality. However these effects would be expected to be short lived with sediment quickly settling out of the water column.	3 low
Discharges to sea (planned) Sediment fouling	The main impact from return of produced sand to sea will be the smothering of the seabed which negatively affects benthic species. Unlike the accidental release, planned returned of produced sand to sea would be expected to involve greater quantities which would have more significant potential to affect benthic species through sea-bed smothering. These environments are expected to recover quickly and repopulate from surrounding areas once the process completes.	6 moderate

6.4.7 Hydrocarbon and chemicals storage

6.4.7.1 Overview

A distinction is required between the storage of oil and fuels for use in power generation of process equipment and auxiliary engines, and the storage of oil and hydrocarbons both in greater quantities for the main energy generation units, but also where hydrocarbons from production are stored for offtake. The smaller equipment alluded to under the title 'Drilling (with the use of water based muds and oil based muds)' in section 3.5.2 is able to make use of measures such as bunding and containment apparatus. While this is sufficient for storage of smaller quantities of oil and chemicals, for larger storage vessels in excess of 10,000 litres of hydrocarbons, such approaches are ineffective. The process detailed here refers to those quantities of hydrocarbons stored in greater quantities. As greater quantities are stored the associated consequences of an accidental release are also greater. The environmental aspect for this process will be discharges to sea. This includes the Tiered accidental ranking detailed by IPIECA. This was chosen due to its widely accepted classification of accidental risk for the offshore oil and gas industry (see Figure 6.2). Under the guidance, accidents are split into three tiers. These are discussed in Section 6.3.4.1.

6.4.7.2 Measures

- Planning based measures:
  - Environmental Statement with identification of risks and oil spill modelling;
  - Emergency plans, including spill clean-up procedures and accident logs;
  - Dedicated oil-spill response crews contracted to respond at short notice;
  - Training for all personnel onsite; and
  - Exclusion zone around installation to prevent collisions.
- Technical based measures:
  - Double hulled vessels for floating storage to provide added protection during a collision;
  - Strategic placement of tanks within the installation to provide added protection against collisions;
  - Separation between process areas and storage areas with minimum distance for separation (Norsok, 2008); and
  - Drainage systems for capture of spillages including oil separation at bilge tank.

6.4.7.3 Issues

The risk levels for oil storage are presented in Table 6.19.

Table 6.19: Risk and impacts of oil storage

Main Environmental Aspects	Impacts	Risk Level
Impacts to marine ecosystems (accidental) Tier III	Accidental release of large quantities of oil to sea would be likely to have severe impact on marine species. The severity would be such that it could be foreseen that the impact would take a significant amount of time spanning years for the full recovery of the affected marine ecosystems.	4 low

Main Environmental Aspects	Impacts	Risk Level
	According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a catastrophic release from a large storage vessel for use in a risk assessment is $5x10^{-6}$ per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a catastrophic rupture occurring in an offshore atmospheric storage tank to be $3x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.7x10^{-7}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	
Impacts to coastal environments (accidental) Tier III	The accidental release of large quantities of oil to sea would have a high potential for those materials to reach the coastline where the impacts would be extremely severe for not only marine species but avian and terrestrial species within the near shore. The potential damaged caused could have long term (years) effect along the affected coastline with recovery of ecosystems expected to be slow. In some cases such damage may mean that ecosystems do not fully recover to pre-incident conditions. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a catastrophic release from a large storage vessel for use in a risk assessment is $5x10^{-6}$ per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a catastrophic rupture occurring in an offshore atmospheric storage tank to be $3x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.7x10^{-7}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	5 moderate
Impacts to water quality (accidental) Tier III	While hydrocarbons will emulsify and degrade within marine conditions for a tier III event the quantities of oil involved would have severe impact upon the general water quality within the marine environment. The degradation and breakdown of hydrocarbons would be expected to have a strongly negative affect for chemical oxygen demand affecting the ability of seawater to support marine life. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a catastrophic release from a large storage vessel for use in a risk assessment is $5x10^{-6}$ per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a catastrophic rupture occurring in an offshore atmospheric storage tank to be $3x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.7x10^{-7}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	4 low
Seabed fouling (accidental) Tier III	The potential for hydrocarbon spillages to reach the seabed is less clear, but given the quantities involved the potential for seabed fouling should be considered a risk. This would include contamination of marine sediments which have knock-on effects for benthic species that live within them. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a catastrophic release from a large storage vessel for use in a risk assessment is $5x10^{-6}$ per vessel year. This corroborates with data from	4 low

Main Environmental Aspects	Impacts	Risk Level
	the OGP (2010a), which estimate the probability of a catastrophic rupture occurring in an offshore atmospheric storage tank to be $3x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.7x10^{-7}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	
Impacts to marine ecosystems (accidental) Tier II	Accidental release of large quantities of oil to sea would be likely to have impact on marine species. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a major release from a large storage vessel for use in a risk assessment is $1x10^{-4}$ per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a major spill occurring in an offshore atmospheric storage tank to be between $1.6x10^{-6}$ and $2.8x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.3x10^{-6}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	4 low
Impacts to coastal environments (accidental) Tier II	The accidental release of large quantities of oil to sea would have a high potential for those materials to reach the coastline, the impacts would be for not only marine species but avian and terrestrial species within the near shore. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a major release from a large storage vessel for use in a risk assessment is $1x10^{-4}$ per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a major spill occurring in an offshore atmospheric storage tank to be between $1.6x10^{-6}$ and $2.8x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.3x10^{-6}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	4 low
Impacts to water quality (accidental) Tier II	While hydrocarbons will emulsify and degrade within marine conditions for a tier II event the quantities of oil involved would have an impact upon the general water quality within the marine environment. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a major release from a large storage vessel for use in a risk assessment is $1x10^{-4}$ per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a major spill occurring in an offshore atmospheric storage tank to be between $1.6x10^{-6}$ and $2.8x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.3x10^{-6}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	4 low
Seabed fouling (accidental) Tier II	The potential for hydrocarbon spillages to reach the seabed is less clear, but given the quantities involved the potential for seabed fouling should be considered a risk. This would include contamination of marine sediments which have knock-on effects for benthic species that live within them. According to the UK Health and Safety Executive (HSE) (2012), the recommended rate of a major release from a large storage vessel for use in a risk assessment is $1x10^{-4}$	4 low

Main Environmental Aspects	Impacts	Risk Level
	per vessel year. This corroborates with data from the OGP (2010a), which estimate the probability of a major spill occurring in an offshore atmospheric storage tank to be between $1.6x10^{-6}$ and $2.8x10^{-6}$ per tank per year and for a pressurised storage vessel to be $4.3x10^{-6}$ per vessel per year. For this reason, the likelihood of a Tier III event from this source is judged as 'extremely rare'.	

6.4.8 Diesel/chemical deliveries/loading

6.4.8.1 Overview

Diesel is often required for auxiliary power generation on the platform. Additionally, chemicals are required for use in drilling and in some cases, enhanced recovery. These substances must be delivered to the platform via shipping. The loading of diesel and chemical deliveries presents a risk of a spillage occurring during transfer. The quantities of liquid involved are significantly lower than the volumes of unprocessed hydrocarbons handled on the platform. For this reason, spills during chemical and diesel loading / unloading are classified as a Tier I event under the IPIECA guidance - discussed in Section 6.3.4.1.

6.4.8.2 Measures

- Planning based measures:
  - Emergency plans, including spill clean-up procedures and accident logs; and
  - Training for all personnel onsite.
- Technical based measures:
  - Double hulled vessels for delivery vessels to provide added protection;
  - Strategic placement of tanks within the installation and ship to provide added protection against collisions; and
  - Drainage systems for capture of spillages.

6.4.8.3 Issues

The risk levels for diesel/chemical deliveries are presented in Table 6.20.

Table 6.20: Risk and impacts of diesel/chemical deliveries

Main Environmental Aspects	Impacts	Risk Level
Impacts to marine ecosystems (accidental) Tier I	Accidental releases of diesel or chemicals oil to sea would be likely to have an impact on marine species. The severity would be limited due to the small quantities involved and rapid dilution[85]. In their risk assessment data directory, the OGP (2010a) estimate that the probability of an offshore diesel storage tank rupturing to be $3.0x10^{-5}$ per tank per year. On this basis, the likelihood of spillage involving diesel or chemicals is judged as 'rare'.	6 moderate

[85] Refer to section 1.4.3 on cumulative impacts.

Main Environmental Aspects	Impacts	Risk Level
Impacts to coastal environments (accidental) Tier I	The accidental release of diesel or chemicals to sea would have some potential for those materials to reach the coastline, where the impacts would be amplified due to the avian and terrestrial species within the near shore. In their risk assessment data directory, the OGP (2010a) estimate that the probability of an offshore diesel storage tank rupturing to be 3.0×10^{-5} per tank per year. On this basis, the likelihood of spillage involving diesel or chemicals is judged as 'rare'.	8 moderate
Impacts to water quality (accidental) Tier I	Hydrocarbons will emulsify and degrade within marine conditions, therefore for a tier I even the quantities of diesel/chemicals involved would have a limited impact upon the general water quality within the marine environment. In their risk assessment data directory, the OGP (2010a) estimate that the probability of an offshore diesel storage tank rupturing to be 3.0×10^{-5} per tank per year. On this basis, the likelihood of spillage involving diesel or chemicals is judged as 'rare'.	4 low
Seabed fouling (accidental) Tier I	The potential for hydrocarbon spillages to reach the seabed is less clear; given the quantities involved the potential for seabed fouling should be considered a small risk. In their risk assessment data directory, the OGP (2010a) estimate that the probability of an offshore diesel storage tank rupturing to be 3.0×10^{-5} per tank per year. On this basis, the likelihood of spillage involving diesel or chemicals is judged as 'rare'.	4 low

6.4.9 Open loop cooling systems

6.4.9.1 Overview

Open loop cooling systems make use of sea-water (usually taken from depth where the water is colder) to circulate within cooling systems for process equipment. To ensure the integrity of the pipework used for this process it is also necessary to make use of antifoulant chemicals. The 'used' cooling water at the end of the process is then returned back to the sea on the basis that it represents low risk to the environment. The environmental aspects for this process are:

- Discharges to the sea – thermal effects of returning warmer water to cold sea conditions; and
- Discharges to the sea – trace quantities of anti-foulant chemicals within the water extracted.

6.4.9.2 Measures

- Use of caisson to discharge the used water at depth where the thermal effects of the used water will be dissipated more quickly; and
- The use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM) as anti-foulant, to reduce the potential impact on marine species.

6.4.9.3 Issues

The risk levels for open loop cooling systems are presented in Table 6.21.

Table 6.21: Risk and impacts of open loop cooling systems

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (planned) – Thermal affects - Marine biodiversity	The effects of returning water to sea which is thermally different to surrounding conditions can have both negative and positive effects on the marine species and biodiversity of receiving ecosystem. However the effects would be expected to be short lived and confined to the area immediately around the release pipe.	4 low
Discharges to sea (accidental) – residual antifoulant - Marine biodiversity	Anti-foulant chemicals are required to maintain the integrity of the cooling system. The quantities and nature of the chemicals used will typically be selected according to chemical use approval requirements under international conventions (e.g. PLONOR list of chemicals under OSPAR, the zero discharge principle under HELCOM), although requirements vary across the EU. Concentrations within released water would be expected to be of a concentration where effects were limited, with further dilution quickly reducing any potential impact[86].	4 low

6.4.10 **HVAC cooling systems**

6.4.10.1 Overview

Heating, ventilation and air conditioning systems used in the living quarters of the installation will make use of refrigerant gases to maintain the system. Typically the use of refrigerant gases for air conditioning use hydrofluorocarbons (HFCs) covered by the EU Fluorinated gases regulation (greenhouse gases). Containment of gases within air conditioning systems is difficult with office air conditioning requiring 're-charging' and maintenance on a regular basis. This will also be true for offshore installations. The key environmental aspect in this process will be:

- Releases of fluorinated gases to air which have the potential to contribute to global warming.

6.4.10.2 Measures

- Regulatory compliance under the EU 'Fluorinated gases regulation (Regulation (EU) 517/2014[87]). These include:
    - Use of fluorinated gases with lower global warming potentials as set out within Annex I of EU Regulation 517/2014;
    - Maintain suitable maintenance of air conditioning systems; servicing and repairs must be completed by accredited engineers as per Article 10 of EU Regulation 517/2014;
    - Record keeping and reporting for use of F-gases;
    - Use of leak detection systems for early identification of leaks; and
    - Labelling of storage containers that hold F-gases.

6.4.10.3 Issues

The risk levels for HVAC cooling systems are presented in Table 6.22.

[86] Refer to section 1.4.3 on cumulative impacts.
[87] Regulation on the use of fluorinated gases 'http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.150.01.0195.01.ENG

Table 6.22: Risk and impacts of HVAC cooling systems

Main Environmental Aspects	Impacts	Risk Level
Releases to air (unplanned) – leaking air conditioning equipment	Fluorinated gases have significantly greater global warming potential than carbon dioxide (per kg). The EU F-gas regulation is intended to put in place measures to limit the impact of these substances through better control and maintenance and the use of gases with lower potentials. The overall contribution of fluorinated gases to air from offshore installations is generally expected to be relatively low and less greenhouse gas intense than activities such as flaring.	4 low

6.4.11 **Topside drainage systems**

6.4.11.1 Overview

Drainage systems on-board the installation will be key to managing the flow of wastes and spilt materials. Broadly the drainage systems can be categorised into three types:

- Sewer systems – manages the flow of grey (water from showers, kitchens, and domestic sinks) and black water (sewage);
- Closed systems – drainage systems situated around the process equipment for loss of hydrocarbons. These materials feedback into the process up-stream; and
- Open systems – drainage systems for capture of spills in storage areas on deck.

The flows generated from the sewer systems are typically released to sea after treatment as a low environmental risk substance. The flows collected from the closed systems are further processed and returned to the processing phase if possible or retained as waste otherwise. For open systems capture and treatment systems are put in place. The environmental aspect from this process is

- Discharges to sea as a result of drainage systems failing to capture lost material/overflowing and discharging to sea.

6.4.11.2 Measures

General

- Design of drainage systems to manage the flow of different types of material which pose different hazards.

Sewer systems

- Following the requirements of Annex IV of Marpol, installations are required to be equipped with either an approved sewage treatment plant or an approved sewage comminuting and disinfecting system or a sewage holding tank.

Closed systems

- Gully-pots to capture solid materials and prevent blockage of the drainage for flow down into bilge tanks;
- Bilge tanks with capability for oil and water separation to manage the flow of lost materials; and
- A closed drains drum analyser for monitoring the contents of the liquids held in the bilge tank (Ffyne, 2014).

Open Systems

- Drip trays drip to capture any spillage of flammable or hazardous liquids;

- Gully-pots to capture solid materials and prevent blockage of the drainage for flow down into bilge tanks;
- Bilge tanks with capability for oil and water separation to manage the flow of lost materials;
- Valve systems to prevent back-flow and loss to the sea; and
- An open drains drum analyser will monitor the contents of the liquids held in the bilge tank (Ffyne, 2014).

6.4.11.3 Issues

The risk levels for topside drainage systems are presented in Table 6.23.

Table 6.23: Risk and impacts of top side drainage systems cooling systems

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) – Tier I – Minor incident – damage to marine environment	Tier I accidents represent those with the highest frequency but lowest severity. The accidental discharge of drainage systems in this case may include waters contaminated with hydrocarbons or production chemicals. The quantities involved would be expect to be more limited but have the potential to still cause significant impact on marine species.	8 moderate
Discharges to sea (accidental) – Tier I – Minor incident – damage to coastal environment	For Tier I accidents the quantities of material involved would be expected to be smaller than the major spillages described in earlier processes. The potential for discharged material to reach the coastline is also more limited. However because the frequency of the incident is rare the overall risk ranking is judged to be generally low.	4 low
Discharges to sea (accidental) – Tier I – Moderate incident – damage to water quality	For Tier I accidents the quantities of material involved would be expected to be smaller than the major spillages described in earlier processes. The effects on water quality would be expected to be short lived with minor impact.	3 low
Discharges to sea (accidental) – Tier I – Minor incident – fouling seabed marine environment	The impact for seabed fouling relates to smothering of surface layers where benthic species live. For tier I accidents where the likely discharged material is drainage waters contaminated with hydrocarbons or chemical wastes, the likelihood for seabed fouling is lower.	2 low

6.4.12 **Waste management**

6.4.12.1 Overview

Waste management will cover all wastes generated on the installation ranging from low hazard waste such as packaging, and metal scraps to higher risk waste such as oil contaminated muds and chemical wastes from processing operations. The wastes created are generally stored within sealed containers for return to shore to be processed. There is potential for loss of containment and release to environment:

i. From a loss of containment of the storage container while on-board;

ii. Dropped or lost containers during transfer to shipping vessels for return to shore; and

iii. Loss of containment following collision.

6.4.12.2 Measures

- Waste Management Plan to document and control all wastes generated as part of the installations work;
- Processing of waste to reduce quantity e.g. dewatering for oil based muds;
- Training for personnel on waste handling procedures (particularly for liquid wastes); and
- Design of waste containers (closed-skin skips, bins, Intermediate Bulk Containers (IBCs), containers, totes, etc.) to prevent loss.

6.4.12.3 Issues

The risk levels for waste management are presented in Table 6.24.

Table 6.24: Risk and impacts of waste management

Main Environmental Aspects	**Impacts**	**Risk Level**
Discharges to sea (accidental) – Liquid wastes - Marine biodiversity	The accidental discharge of liquid wastes may include waters contaminated with hydrocarbons or production chemicals. The quantities involved would be expected to be limited but have the potential to still cause impact on marine species. However the effects would be expected to be short lived.	2 low
Discharges to sea (accidental) – Liquid wastes - Deterioration in water quality	The accidental discharge of liquid wastes may include waters contaminated with hydrocarbons or production chemicals. The quantities involved would be expected to be limited but have the potential to still cause impact on water quality. However the effects would be expected to be short lived.	2 low
Discharges to sea (accidental) – Liquid wastes - Sediment fouling	The quantity discharged and nature (liquid) of the waste lost to sea mean the potential to reach the seabed could be expected to be a minor issue. Quantities reaching the seabed would have only limited impact.	2 low
Discharges to sea (accidental) – solid waste - Marine biodiversity	The accidental discharge of solid wastes would be likely to include drilling muds, oil contaminated cuttings or solid waste. These materials will have impacts on marine species both from the physical effects on water (turbidity) and the chemical effects of the contaminated materials. Depending on the quantities involved the impact for marine species could be significant.	6 moderate
Discharges to sea (accidental) – solid waste - Sediment fouling	The accidental discharge of solid wastes would be likely to include drilling muds, oil contaminated cuttings or solid waste. These materials will have the potential for seabed smothering affecting benthic species as well as toxic effects from the contaminated material itself. The potential impact for this risk is potential significant depending on quantities involved.	6 moderate

6.4.13 **Off-take of oil by shipping vessels**

6.4.13.1 Overview

During the off-take of oil by shipping vessels, the oil held on the installation within hydrocarbon tanks is pumped on board the ship. This is a process that can take several hours to complete with the shipping vessel held in place at sea for the duration. Based on the IPIECA tiered system for accident severity, given the quantities of oil and gas that can be involved in transfers the severity ranking is up to Tier III. This would represent a loss of oil and/or gas to sea as a result of containment failure, collision, or human error. The key environmental aspect are:

- Discharges to sea as a result of accidental loss. Quantities involved would be expected to be significant.

6.4.13.2 Measures

- Planning based measures:
    - Environmental Statement with identification of risks and oil spill modelling specific to the site;
    - Emergency plans, including spill clean-up procedures and accident logs;
    - Dedicated oil-spill response crews contracted to respond at short notice;
    - Training for all personnel onsite; and
    - Exclusion zone around installation to prevent collisions.
- Technical based measures:
    - Double hulled vessels for floating storage to provide added protection during a collision;
    - Strategic placement of tanks within the installation to provide added protection of collisions; and
    - Quick release valves which can be triggered remotely.

6.4.13.3 Issues

The risk levels for off-take off by shipping vessels are presented in Table 6.25.

Table 6.25: Risk and impacts of off take by shipping vessels

Main Environmental Aspects	Impacts	Risk Level
Impacts to marine ecosystems (accidental) Tier III	With expected risk management measures in place, an accidental release of large quantities of oil to sea would still have a serious impact on marine species, but more catastrophic impacts would be adverted. Additionally, the likelihood of this incident would be very low with measures in place. A tier III spill from a shuttle tanker has never occurred and therefore the likelihood is judged to be 'extremely rare'.	4 low
Impacts to coastal environments (accidental) Tier III	With measures in place, the chances of an accidental release of large quantities of oil to sea occurring would be greatly reduced and in the event of a spill the quantity of fluid leaked to the ocean would also be reduced by response measures. However, if even small quantities of hydrocarbons were to reach the coastline, the impacts would be significant for not only marine species but also avian and terrestrial species within the near shore. The potential damaged caused could also have prolonged effects along the affected coastline. A tier III spill from a shuttle tanker has never occurred and therefore the likelihood is judged to be 'extremely rare'.	5 moderate

Main Environmental Aspects	Impacts	Risk Level
Impacts to water quality (accidental) Tier III	Hydrocarbons will emulsify and degrade within marine conditions. With measures in place, the quantities of oil involved would therefore not have a great effect on general water quality within the marine environment. The likelihood of a spill occurring is also very low when measures are in place. A tier III spill from a shuttle tanker has never occurred and therefore the likelihood is judged to be 'extremely rare'.	3 low
Seabed fouling (accidental) Tier III	The potential for hydrocarbon spillages to reach the seabed is less clear, but given the small quantities involved with measures in place, and the low likelihood of a spill, the potential for seabed fouling should be considered a great risk. A tier III spill from a shuttle tanker has never occurred and therefore the likelihood is judged to be 'extremely rare'.	3 low

6.4.14 **Off-take of oil by pipeline**

6.4.14.1 Overview

The alternative to off-take by shipping vessel is to use pipelines for transfer of oil and gas back to shore. Depending on the location of the offshore installation the piping network required to return oil and gas to shore can run for hundreds of miles. Shut-off valves within the pipework can therefore be placed at considerable distances apart with material flowing the full length of the pipework. Loss of oil to the marine environment during this process can occur at two points, firstly during the feed of oil into the pipeline network, and secondly from pipeline failure and rupture. Both points have the potential to release considerable amounts of oil to the natural environment resulting in a significant amount of damage. Based on the IPIECA scale the tiered level of severity is ranked at tier III.

6.4.14.2 Measures

- Planning based measures:
  - Environmental Statement with identification of risks and oil spill modelling;
  - Emergency plans, including spill clean-up procedures and accident logs;
  - Dedicated oil-spill response crews contracted to respond at short notice; and
  - Training for all personnel onsite.
- Technical based measures:
  - Quick release valves which can be triggered remotely;
  - Use of 'Pigs' which are intelligent robotic devices that are propelled down pipelines to evaluate the interior of the pipe. Pigs can test pipe thickness, roundness, check for signs of corrosion, detect minute leaks, and any other defect along the interior of the pipeline that may either restrict the flow of gas, or pose a potential safety risk for the operation of the pipeline (Devold, 2013); and

- Pipeline protection mechanisms such as 'trenching, rock dumping and concrete mattresses'.

6.4.14.3 Issues

The risk levels for off-take of oil by pipeline are presented in Table 6.26.

Table 6.26: Risk and impacts of off take of oil by pipeline

Main Environmental Aspects	Impacts	Risk Level
Impacts to marine ecosystems (accidental) Tier III	Accidental release of large quantities of oil to sea would be likely to have severe impact on marine species. The severity would be such that it could be foreseen that the impact would take a significant amount of time spanning years for the full recovery of the affected marine ecosystems. According to the OGP's (2010a) Risk Assessment Data Directory for riser and pipeline release frequencies, the probability of a subsea pipeline failure in open sea is between 1.4×10^{-5} and 5.0×10^{-4} per km-year. On this basis, the likelihood of a tier III spill from a pipeline is deemed to be 'rare'.	8 moderate
Impacts to coastal environments (accidental) Tier III	The accidental release of large quantities of oil to sea would have a high potential for those materials to reach the coastline where the impacts would be extremely severe for not only marine species but avian and terrestrial species within the near shore. The potential damaged caused could have long term (years) effect along the affected coastline with recovery of ecosystems expected to be slow. In some cases such damage may mean that ecosystems do not fully recover to pre-incident conditions. According to the OGP's (2010b) Risk Assessment Data Directory for riser and pipeline release frequencies, the probability of a subsea pipeline failure in open sea is between 1.4×10^{-5} and 5.0×10^{-4} per km-year. On this basis, the likelihood of a tier III spill from a pipeline is deemed to be 'rare'.	10 high
Impacts to water quality (accidental) Tier III	While hydrocarbons will emulsify and degrade within marine conditions for a tier III event the quantities of oil involved would have severe impact upon the general water quality within the marine environment. The degradation and breakdown of hydrocarbons would be expected to have a strongly negative affect for chemical oxygen demand affecting the ability of seawater to support marine life. According to the OGP's (2010b) Risk Assessment Data Directory for riser and pipeline release frequencies, the probability of a subsea pipeline failure in open sea is between 1.4×10^{-5} and 5.0×10^{-4} per km-year. On this basis, the likelihood of a tier III spill from a pipeline is deemed to be 'rare'.	6 moderate

Main Environmental Aspects	Impacts	Risk Level
Seabed fouling (accidental) Tier III	The potential for hydrocarbon spillages to reach the seabed is less clear, but given the quantities involved the potential for seabed fouling should be considered a risk. This would include contamination of marine sediments which have knock-on effects for benthic species that live within them. According to the OGP's (2010b) Risk Assessment Data Directory for riser and pipeline release frequencies, the probability of a subsea pipeline failure in open sea is between 1.4×10^{-5} and 5.0×10^{-4} per km-year. On this basis, the likelihood of a tier III spill from a pipeline is deemed to be 'rare'.	6 moderate

6.4.15 **Off-take of gas by pipeline**

6.4.15.1 Overview

Off-take for oil and gas by pipeline has been separated into two different processes as the potential environmental risks are different. In practice pipelines can be used to transport both oil and gas comingled for separation on shore. For gas only pipelines, the same issues are apparent for release, a loss at the point of feed into the pipeline and a loss as a result of pipeline failure and rupture at a point between the installation and shore. As with oil pipelines depending on the location of the installation the pipelines can run for hundreds of miles with shut-off valves at points along the pipeline. These can potentially be several miles apart allowing the contents of the pipe between the value and the rupture to leak to environment. The loss of gas from pipelines will affect the releases to air environment aspect; however gas will also carry a quantity of liquid condensate which would also be lost to environment. It is assumed that all actions to reduce condensate before transmission will be taken and that any condensate lost to environment will quickly dissipate with little affect. The main issue will therefore be quantities of hydrocarbon gas lost to atmosphere.

6.4.15.2 Measures

- Pipeline isolation/shut-in mechanisms;
- Leak detection systems; and
- Pipeline inspection and maintenance programme.

6.4.15.3 Issues

The risk levels for off-take of gas by pipeline are presented in Table 6.27.

Table 6.27: Risk and impacts of off take of gas by pipeline

Main Environmental Aspects	Impacts	Risk Level
Releases to air (accidental) – containment failure in pipeline (contribution to global emissions for greenhouse gas)	Rupture of pipelines or loss of containment will cause hydrocarbon gases to vent to the surface of the sea and then to the atmosphere. These gases will contain substances will contribute to climate change. Depending on where the rupture occurs the quantities of gas released could be significant but the likely frequency of such an event is rare.	4 low

6.4.16 Enhanced recovery - water flooding using seawater

6.4.16.1 Overview

This involves injection of water to sweep the hydrocarbon reserve and boost production from the primary well, by displacing trapped oil. Large volumes of water are required, which must be treated, pressurised and injected. This increases the amount of water produced from the well, which in turn increases the amount that must be treated and discharged (see 8.5 produced water management). As with onshore water flooding, there is a small risk of induced seismicity (Rubinstein & Mahani, 2015) which may result in underwater noise.

6.4.16.2 Measures

- BAT technology for low sulphur fuels in vehicles and pressurising equipment;
- Use of hydrocyclones to remove hydrocarbon content within produced water and return hydrocarbon fraction to upstream processing;
- Sampling and analysis of hydrocarbon contaminated water to ensure hydrocarbon content is below 30 mg/l (OSPAR, 2014) or equivalent thresholds under HELCOM (15 mg/l in most cases) or the Barcelona Convention (40 mg/l); and
- Maintenance and system checks of containment systems used for processing.

6.4.16.3 Issues

The risk levels for water flooding using seawater are presented in Table 6.28. The impacts for the aspect 'discharges to sea' are covered in 8.5, produced water management. The impacts for the aspect 'under water noise in the marine environment (disturbance to animals) are covered in '5.2 drilling using water based muds'.

Table 6.28. Risk levels of water flooding using seawater

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality) – injection equipment	Emissions of SO_2, NOx and dust from the equipment and vehicles used to clean, pressurise and inject water	4 low
Releases to air (contribution to global warming) – injection equipment	Emissions of CO_2 from the equipment used to pressurise and clean injection water.	3 low
Underwater noise in the marine environment resulting from induced seismicity (disturbance to animals)	As with onshore water flooding, there is a small risk of induced seismicity (Rubinstein & Mahani, 2015). This is due to the pressures applied in order to inject the water. This may result in low levels of underwater noise.	2 low

6.4.17 Enhanced recovery (miscible gas injection)

6.4.17.1 Overview

This involves injection of hydrocarbon gas into the well to boost production rates and overall recovery factor. Emissions are generated by equipment for separation, compression and injection. This does not eliminate the need to manage produced hydrocarbon gas, as a proportion of the injected gas will be dissolved in oil collected in the future; therefore management measures including flaring are still required (see 'Well bore clean-up'). As with onshore enhanced recovery, there is a small risk of induced seismicity (Rubinstein & Mahani, 2015) which may result in underwater noise.

6.4.17.2 Measures

- BAT technology for low sulphur fuels in vehicles and pressurising equipment;
- BAT for use of flaring including maintenance and ensuring efficient running of the equipment in place; and
- Planned and metered flaring to avoid excess flaring requirements.

6.4.17.3 Issues

The risk levels for miscible gas injection using HCs are presented in Table 6.29. The impacts for the aspect 'under water noise in the marine environment (disturbance to animals) are covered in '5.2 drilling using water based muds'.

Table 6.29: Risk levels for enhanced recovery (miscible gas injection)

Main Environmental Aspects	Impacts	Risk Level
Releases to air (local air quality) - injection equipment	Emissions of SO_2, NOx and dust from the equipment and vehicles used to clean, pressurise and inject gas	4 low
Releases to air (contribution to global warming) - injection equipment	Emissions of CO_2 from the equipment used to pressurise clean and inject gas.	3 low
Underwater noise	Underwater noise in the marine environment resulting from induced seismicity affecting marine fauna.	4 low

6.4.18 Well stimulation (low volume hydraulic fracturing)

Relatively low volumes of water together with a proppant such as sand and other chemicals including thickening agents and surfactants, are injected into the well to fracture the formation containing the hydrocarbons. Associated environmental hazards arise from the need to store additional chemicals onsite (see 8.9 hydrocarbon and chemical storage – Tier 1 only due to relatively low volumes) and treat the flowback. Underwater noise resulting from induced seismicity may also cause a disturbance to sea mammals.

6.4.18.1 Measures

- The use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR or the zero discharge principle under HELCOM[55]);
- BAT technology for low sulphur fuels in vehicles and pressurising equipment;

- Bunding, protected skids and totes for fluid storage;
- Maintenance programmes for all equipment;
- Use of hydrocyclones to remove hydrocarbon content within produced water and return hydrocarbon fraction to upstream processing;
- Sampling and analysis of hydrocarbon contaminated water to ensure hydrocarbon content is below 30 mg/l (OSPAR, 2014) or equivalent thresholds under HELCOM (15 mg/l in most cases) or the Barcelona Convention (40 mg/l);
- Maintenance and system checks of containment systems used for processing;
- In well filtration systems such as 'slotted liners with screens' to reduce sand generated;
- In the context of induced seismicity and well integrity, application of the draft revision of ISO/TS 16530-2:2014 'Well integrity – Part 2: Well integrity for the operational phase';
- 'Soft-start' operations;
- Methane monitoring[88]; and
- Flaring to control methane flux following fracturing.

Note that, while increasingly used onshore, reduced emissions completions ("green completions") are not considered as viable offshore[89].

6.4.18.2 Issues

The risk levels for low volume hydraulic fracturing are presented in Table 6.30. The impacts for the aspect 'discharges to sea – hydrocarbon and chemical storage –Tier 1 spill' are covered in 8.9, and the impacts for the aspect 'under water noise in the marine environment (disturbance to animals) are covered in '5.2 drilling using water based muds'.

[88] This includes a characterisation of background methane levels and then the implementation of technical monitoring measures coupled with a leak detection and repair programme.
[89] See for example: http://www.ipieca.org/energyefficiency/solutions/78161.

Table 6.30: Risks and impacts of low volume hydraulic fracturing

Main Environmental Aspects	**Impacts**	**Risk Level**
Discharges to sea of flowback (accidental) Marine biodiversity/ habitat loss	Impacts from the accidental discharge of flowback on marine environments assumes that the flowback has not been fully treated. Dependent on the quantity of flowback discharged to sea the impacts could be significant. Assuming this is the case the overall risk rating for this risk is judged to be generally moderate.	6 moderate
Discharges to sea of flowback (accidental) Coastal biodiversity/ habitat loss	The impact involves the discharged material to sea reaching coastal environments and then causing impact for coastal species both within the marine environment but also avian and terrestrial species in the near-shore. Based on the measures in place the potential to cause impact this is considered minor based on the risk matrix, and likely occurrence of coastal impacts would be rare.	4 low
Discharges to sea of flowback (accidental) Deterioration in water quality	Untreated flowback will be contaminated with chemicals, proppants and hydrocarbons. Direct impacts on water quality as a result of accidentally discharged fluids are expected to be short lived due to high levels of dilution[90] and the use of low-risk chemicals / avoided use of high risk chemicals (where applicable e.g. PLONOR chemicals in the OSPAR region, the zero discharge principle under HELCOM	2 low
Discharges to sea of flowback (accidental) Sediment fouling/benthic habitat smothering	The main issue with accidental loss of flowback will be that it is still contaminated by hydrocarbons, chemicals and proppants. This material will likely remain on the sea surface and form an emulsion with the risk of reaching the sea bed being lower.	2 low
Discharges to sea of flowback (planned – after onsite treatment) Marine biodiversity/ habitat loss	The measures detailed are intended to reduce the hydrocarbon, chemical and proppant content to safe levels. However a full removal is difficult and costly to achieve. Planned release of flowback will still contain trace quantities of hydrocarbons which have the potential to negatively affect marine populations. Risk rating is still moderate, but ranked score is higher for accidental release than for planned releases.	5 moderate
Discharges to sea of flowback (planned – after onsite treatment) Coastal biodiversity/ habitat loss	The impact detailed from this risk involves the material discharged to sea reaching coastal environments and then causing impact for coastal species both within the marine environment but also avian and terrestrial species in the near-shore. Based on the measures in place the potential to cause impact is considered minor based on the risk matrix, and likely occurrence of coastal impacts would be rare.	2 low
Discharges to sea of flowback (planned – after onsite treatment) Deterioration in water quality	The use of the measures detailed will reduce the hydrocarbon, chemical and proppants content of flowback. Direct impacts on water quality as a result of planned discharged produced water are expected to be limited and short lived due to low concentrations.	2 low

[90] Refer to section 1.4.3 on cumulative impacts.

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea of flowback (planned – after onsite treatment) Sediment fouling/benthic habitat smothering	Trace quantities of chemicals, hydrocarbons and proppants in the treated flowback may form an emulsion, with the risk of reaching the sea bed being lower.	2 low
Releases to air (local air quality) - injection equipment	Emissions of SO2, NOx and dust from the equipment and vehicles used to clean, pressurise and inject water.	4 low
Releases to air (contribution to global warming) - injection equipment and fugitive methane	Emissions of CO2 from the equipment used to pressurise clean and inject water. Additionally in gas wells, small quantities of pressurised methane may leak from connection points between containment equipment.	3 low
Underwater noise	Underwater noise in the marine environment resulting from induced seismicity affecting marine fauna.	4 low

6.5 Stage 4 Project cessation and well closure

6.5.1 Summary of environmental risks

The completion of lifecycle stage 3 covers all the processes and technologies required during the production phase for an offshore oil and gas installation. Stage 4 covers those processes and technologies after production has ceased, including the deconstruction of the installation and closure of the well. The following key sub-stage processes and technologies within project cessation and well closure include:

9. Well closure

    9.1 Well plug and abandonment (P&A) tubing recovery

10. Management of cuttings piles

    10.1 Leave in situ with no removal or disturbance

    10.2 Excavation of the pile and recovery to surface/redistribution to another area of the seabed.

Table 6.31: Project cessation and closure

Processes / technologies	Environmental Aspect	Risk characterisation (with expected management measures in place)			Risk characterisation (without expected management measures in place)		
		Likelihood	Consequence	Risk	Likelihood	Consequence	Risk
9. Well Closure							
9.1 Well plug and abandonment (P&A) Tubing recovery	• Discharges to sea[91]	Extremely Rare	Slight	1 low	Extremely rare	Minor	2 low
	• Underwater noise in the marine environment (disturbance to animals)	Rare	Minor	4 low	Occasional	Minor	6 moderate
	• Physical disturbance to seabed: Loss of minor /small items e.g. scaffold within 500m of the platform.[91]	Occasional	Slight	3 low	Occasional	Minor	6 moderate
10. Management of cuttings pile, if present							
10.1 Leave in situ with no removal or disturbance	• Discharges to sea from leaching of hydrocarbons in cuttings piles	Occasional	Minor	6 Moderate	Occasional	Minor	6 moderate
10.2 Excavation of the pile and recovery to surface/redistribution on seabed	• Releases to air – main power generation units (local air quality impacts)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air – main power generation units (emission of greenhouse gas)	Likely	Slight	4 low	Likely	Slight	5 moderate

The list of processes and technologies assessed to have possible impact in stage 4 are:

9.1 Well Plugging;

10.1 Managing cuttings pile – leave in situ; and

10.2 Managing cuttings pile – excavate to surface for removal/redistribute across sea-bed.

Across these technologies and processes the key environmental aspects that have the potential for have for marine life include: discharges to sea, seabed disturbance,

[91] In rough seas, high winds and deep waters, the risk of discharges to sea during well plugging and the loss of small items to sea may increase as margins for error are lower.

releases to air from power generation equipment and noise-generating activities. As with previous life-cycle stages some of the risks identified have common themes throughout offshore oil and gas production with the same measures used to mitigate the risk.

For well plugging the risks of discharges to sea is the same as those discussed during the use of completion fluids (section 6.3), the measures for these specific process are not discussed here, with the additional detail provided in the aforementioned section.

For managing cuttings piles, the options of 'leave in situ' and 'excavate to surface' are relevant. The risks and measures match those for managing drill cuttings (section 6.3). Discussion of these processes is not provided here with greater detail provided in the aforementioned section.

6.5.2 **Well plug and abandonment (P&A) Tubing recovery**

6.5.2.1 Overview

Well plugging is used to seal the well and prevent any residual hydrocarbon loss to the sea. The process involves flooding the well with sea-water and applying plugs (usually made of cement) at various points within the well bore depending on depth and geology. The key risk to the environment from this process will be the leaking of water containing hydrocarbons to sea while plugging is carried out. The key measures to prevent such a leak match those used during the induction of completion fluids to the well.

The conductor is the first section of metal casing inserted into the well bore. This section of casing which protrudes above the seabed and connects with the wellhead is an integral part of the well having the greatest bore diameter and with taking the highest levels of pressure during production. At cessation and well closure it is typically necessary to remove the conductor pipe to ensure that e.g. the first 5 metres below the seabed are the same as the natural surroundings. To remove the conductor a variety of techniques are required including cutting, pulling, twisting and where necessary applying explosives to free the casing. This can then be returned to the topside in one piece or cut into further sections for ease of removal. These processes have a variety of risks for environment with the environmental aspects of seabed disturbance, noise and discharges to sea identified.

6.5.2.2 Measures

- *Noise*: Sound generated from cutting equipment (and, where used, explosives). The majority of measures match those stated for seismic surveys (section 6.2), additional measures will include:
    - Planning to ensure minimum of cutting is needed.
- *Discharges to sea*: Potential discharges to sea from residual hydrocarbons within the well bore during removal of the casing. The measures for this activity match those quoted for drilling (with muds) in section 6.2.3; and
- *Seabed disturbance*: The act of removing the conductor has the potential to create seabed disturbance and debris which could smother the seabed surface for benthic species. Key measures for this risk match those detailed for managing drill cuttings detailed in section 6.2.3.

6.5.2.3 Issues

The risk level for well plugging is presented in Table 6.32.

Table 6.32: Risk and impacts of well plugging

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea (accidental) damage to marine ecosystems	The use of the measures identified including limits on hydrocarbon content of released materials which should also reduce the hazard of the released materials towards marine life. The further dilution[92] of these materials within sea water will continue to reduce the risk of impact.	1 low
Underwater noise in the marine environment (disturbance to animals)	The distinction between physical injury and disturbance that potentially causes behavioural change is important. Seismic surveys within stage 1 have been identified as having the greatest potential to cause physical injury to marine life from noise across the whole off-shore installation life cycle. However activities using heavy equipment (such as cutting tools) have the potential create sufficient noise levels as to have effects on marine species. The risk ranking of generally low is awarded on the basis that relevant measures identified in stage 1 and 2 are deployed.	4 low
Seabed disturbance	Any redistribution of the cuttings pile may cause seabed disturbance. However measures are typically in place to help limit the occurrence of the impact and to protect sensitive areas of seabed from damage. Furthermore on completion of this process, the majority of seabed communities are expected to recover quickly. Sensitive biota such as sponge or cold water coral communities are expected to take additional time to recover from these disturbances compared to other biota. However, with measures in place damage to these species is expected to be minimised.	3 low

6.5.3 **Management of the cutting pile**

6.5.3.1 Overview

Impacts from cuttings piles arise largely due to discharge of OBM-contaminated cuttings. In the OSPAR, HELCOM, Barcelona Convention and Marpol regions, OBM limits apply to discharges (e.g. 1% OPF dry weight on cuttings under OSPAR), which has reduced the potential for formation of new contaminated cuttings piles, therefore the literature suggests this is largely an issue related to historical cuttings piles. Guidelines exist (for example under OSPAR 2006/5) which include quantitative standards (thresholds) for assessing rate of oil loss and persistence from cuttings piles. In the OSPAR region, a 2009 report concluded that disturbance of cuttings piles does not appear to lead to increased impacts on the marine environment and that no specific OSPAR measure should be developed at that time. However, a report for the Joint Industry Programme on cuttings piles (Oil & Gas UK, n.d.) recognises that historical discharge of OBM drill cuttings can create piles with potential for smothering (the major effect) and water column contamination. A range of potential management options for cuttings piles, ranging from removal to leaving in place were identified and that the best option would be decided on a case by case basis following detailed assessment at the time of decommissioning of the installation.

The management of cuttings piles on completion of the project can include leaving 'in-situ', 'excavation back to surface' and 'redistribution on the seabed' depending upon

[92] Refer to section 1.4.3 on cumulative impacts.

the properties of the cuttings pile (hydrocarbon content) and geological formation (risk to shipping vessels). The leave in-situ and extraction options pose the same risks and measures detailed for managing drill cuttings during the well construction phase. For extraction this is because the processes involved are similar to the creation of the cuttings pile, albeit they are reversed. Leaving in-situ presents no further risks that were not considered when the drill cuttings pile was created, although they may apply for a longer timescale.

For redistribution of cuttings, the additional risk relates to the moving of sediment which can further foul and smother the seabed, which will have impacts for benthic communities. Depending on the quantities involved and size of the site, the affected area of seabed has the potential to cover a wide area. For this reason additional measures (detailed below) are required. The aspect relating to releases to air for power generation matches those stated for power generation under life-cycle stage 3 (production) in section 6.4 No further discussion is provided here for that aspect.

6.5.3.2 Measures

- Seabed disturbance:
    - Survey of the cuttings pile and seabed (depending on how recent data is for this aspect); and
    - Environmental impact assessment as part of the decommissioning environmental statement to assess risk and impact and define site specific risk management measures.

6.5.3.3 Issues

The risk levels for managing cuttings piles – leave in situ, excavate or redistribution of material are presented in Tables 6.33 and 6.34.

Table 6.33: Risk and impacts of management of cuttings pile – leave in situ

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea	The cuttings pile released to sea during well drilling would have been required to not exceed maximum concentrations of hydrocarbons (at least since introduction of limits in the OSPAR and HELCOM regions). However this does not mean it is hydrocarbon free. Any remaining residual concentrations have the potential to be released over time into the seawater with potential impacts for marine species and water quality.	6 moderate

Table 6.34: Risk and impacts of management of cuttings pile – excavate to surface/redistribute across seabed

Main Environmental Aspects	Impacts	Risk Level
Releases to air – main power generation units (local air quality impacts)	The use of diesel driven engines to power heavy equipment used for movement of cuttings pile will generate exhaust emissions that potentially affect local air quality. The management of use equipment to ensure that it meets BAT will help limit the impact of such emissions.	2 low

Main Environmental Aspects	Impacts	Risk Level
Releases to air – main power generation units (emissions of greenhouse gas)	The use of diesel driven engines to power heavy equipment used for movement of cuttings pile will generate exhaust emissions that include greenhouse gases and contribute to the overall international emissions of greenhouse gases which contribute to global warming. The management of use equipment to ensure that it meets BAT will help limit the impact of such emissions.	4 low
Seabed disturbance - Physical disturbance to the seabed (redistribution only)	Fouling of sediments and potential smothering of benthic communities and habitat as a result of redistribution the cuttings pile across a large area of seabed.	6 moderate

6.6 Stage 5 Post closure and abandonment

6.6.1 Summary of environmental risks

The previous lifecycle stage describes the processes and technologies required for project cessation and well closure and management of drill cuttings. Completion of life-cycle stage 4 covers cessation of the well processes after which the remaining structures and topside will still remain in place. The final life-cycle stage details the decommissioning and removal of these structures to return the well site back to a suitable state. The following key sub-stage processes and technologies within post closure and abandonment include:

11. Topside and jacket decommissioning:
    - 11.1 Power generation units for all decommissioning activities; and
    - 11.2 Topside/jacket preparation for removal using hot cutting, welding, etc.
12. Decommissioning seabed infrastructure, e.g. pipelines/bundles Pipeline and bundle decommissioning:
    - 12.1 Power generation units for all decommissioning activities;
    - 12.2 Leave pipeline/sections in place (requires rock dumping); and
    - 12.3 Remove mattresses, sandbags, grout bags, and frond mats.
13. Shipping and marine movements for all activities
14. Long-term well integrity:
    - 14.1 Well integrity failure and monitoring.

A summary of risk characteristics for Stage 5 post closure and abandonment are outlined in Table 6.35. Further details of the risk assessment can be found in Appendix B.

Table 6.35: Post closure and abandonment

Processes/ technologies	Environmental Aspect	**Risk Characterisation** (with expected management measures in place)			**Risk Characterisation** (with expected management measures in place)		
		Likelihood	**Consequence**	**Risk**	**Likelihood**	**Consequence**	**Risk**
11. Topside decommissioning							
11.1 Power generation units for all decommissioning activities	• Releases to air – main power generation units • (local air quality impacts)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air – main power generation units • (emissions of greenhouse gas)	Likely	Slight	4 low	Likely	Slight	5 moderate
11.2 Topside preparation for removal using hot cutting, welding etc.	• Discharges to sea[93]	Rare	Slight	2 low	Rare	Slight	2 low
	• Seabed disturbance[93]	Extremely Rare	Moderate	3 low	Extremely Rare	Moderate	3 low
	• Underwater noise	Likely	Slight	2 low	Highly likely	Slight	3 low
12. Decommissioning seabed infrastructure, e.g. pipelines/bundles Pipeline and bundle decommissioning							
12.1 Power generation units for all decommissioning activities	• Releases to air – main power generation units • (local air quality impacts)	Rare	Slight	2 low	Occasional	Slight	3 low
	• Releases to air – main power generation units • (emissions of greenhouse gas)	Likely	Slight	4 low	Likely	Slight	5 moderate
12.2 Leave pipeline/sections in place (requires rock dumping)	• Seabed disturbance – use of rock dumping to secure platform[94]	Occasional	Moderate	9 high	Occasional	Moderate	9 high
12.3 Remove	• Noise – induced seismicity in	Occasional	Minor	6 Moderate	Likely	Minor	8 moderate

93 In rougher seas, high winds and cold temperatures, the chances of accidental discharges to sea and seabed disturbance caused by dropped equipment may be higher, as there are lower margins for error.

94 In deeper and rougher waters, rock dumping may be more inaccurate, resulting in an increased likelihood of seabed disturbance.

mattresses, sandbags, grout bags, and frond mats	the marine environment (disturbance to animals)						
13. Shipping and marine movements for all activities							
14.1 All decommissioning activities	• Releases to air – main power generation units (local air quality impacts)	Rare	Slight	2 low	Rare	Slight	2 low
	• Releases to air – main power generation units (emissions of greenhouse gas)	Likely	Slight	4 low	Likely	Slight	4 low
	• Discharges to sea (containment failure on shipping)[95]	Occasional	Minor	6 moderate	Occasional	Moderate	9 high
	• Discharges to sea (containment failure on rig)[95]	Rare	Slight	2 low	rare	Minor	4 low
	• Seabed disturbance (anchoring)[96]	Likely	Slight	4 low	Likely	Slight	4 low
14. Long-term well integrity							
14.1 Well integrity failure and monitoring	• Discharges to sea (accidental) - leakage of hydrocarbon liquids	Rare	Minor	4 low	Rare	Moderate	6 moderate
	• Releases to air (contributions to climate change) (accidental) – methane leakage	Rare	Minor	4 low	Occasional	Minor	6 moderate

[95] In rough seas and high winds containment failures on shipping and the rig may be more likely due to decreased margins for operator error and stress on equipment.
[96] In rough seas anchoring may cause more damage to the seabed, as it is dragged across a greater area.

Table 6.36 provides a list of processes and technologies assessed to have possible impact in stage 5. In a number of cases the nature and level of the risk identified mirrors similar processes already discussed in previous stages of the life-cycle. In these cases the measures that are used to the control the risk will also be the same. To avoid duplication, Table 6.36 provides details of where further discussion can be found in earlier sections and details the remaining processes within this part of the report.

Table 6.36: processes and technologies within life-cycle stage 5 (Post closure and abandonment) that may have potential risks and impacts

No.	Processes description	Detailed here	Environmental Aspect	If not detailed in this section, discussion can be found under section number and title:
11.1	Power generation units for all decommissioning activities		Releases to air	6.3 'Drilling (with use of water based muds and oil and based muds)
11.2	Topside preparation for removal using hot cutting, welding etc. Dismantling	√		
12.1	Power generation units for all decommissioning activities		Releases to air	6.3 'Drilling (with use of water based muds and oil and based muds)
12.2	Leave pipeline/sections in place (requires rock dumping)		Noise and seabed disturbance from further rock dumping and physical presence	6.3. 'Positioning of apparatus of the seabed'
12.3	Remove mattresses, sandbags, grout bags, and frond mats		Seabed disturbance and noise	6.3. 'Positioning apparatus on seabed'
13.1	All marine shipping		Releases to air	6.2 'Marine Transport'
			Seabed disturbance	6.3 'Positioning of rig on seabed'
			Discharges to sea loss of containment on rig	6.4 'storage of hydrocarbons and chemicals'
14.1	Long-term well integrity failure	√		

6.6.2 Topside preparation for removal using hot cutting, welding etc.

6.6.2.1 Overview

The first process in the removal of topside structures covers all of the preparatory activities to make sure the structure is ready for dismantling. This includes activities such as flushing tanks and process equipment to ensure no remaining hydrocarbons or process chemicals are on-board, the removal of any waste cargo from the site and the dismantling of structures such as Derricks which may require hot cutting and welding. During this set of activities the key environmental aspect will be discharges to sea. For the flushing of tanks, any residual contents will typically follow the same plan as management of produced water with strict guidelines on hydrocarbon concentrations in materials which either have to be retained as waste or discharged to sea following treatment as per the requirements of OSPAR/HELCOM (see 2.4.2.3 for details on hydrocarbon carbon limits under each). No such limits have been identified under the Bucharest Convention.

For hot cutting and welding activities there are a limited number of measures which are detailed below.

6.6.2.2 Measures

- Decommissioning plan for removal of structures on the topside as necessary. Including risk assessment and determination of site specific risk management measures within the environmental statement for decommissioning; and
- Training for personnel to ensure suitable level of competence.

6.6.2.3 Issues

The risk level for topside preparation for removal using hot cutting, welding, etc. is presented in Table 6.37.

Table 6.37: Risk and impacts of topside preparation for removal using hot cutting, welding etc.

Main Environmental Aspects	**Impacts**	**Risk Level**
Discharges to sea	The use of the measures identified including the use of low hazard/risk chemicals and avoided use of high risk chemicals (e.g. PLONOR chemicals under OSPAR, the zero discharge principle under HELCOM), limits on hydrocarbon content of released materials and oil and water separation systems should also reduce the hazard of the released materials towards marine life. The further dilution[97] of these materials within sea water will continue to reduce the risk of impact.	2 Low
Seabed disturbance	This environmental aspect relates to the physical disturbance to the seabed and cuttings pile, if present from dropped objects (e.g. Module loss during lifting and transportation, loss of metal debris) during the dismantlement of topside structures. These kinds of incidents can be avoided in part through training and management plans which are supported in part by accident logs from other decommissioning projects	3 low
Underwater noise	Underwater noise: cutting of jacket/topside to facilitate removal may generate some noise which can carry into the marine environment with potential impacts on marine species, especially cetaceans. However the levels of activity detailed are likely to be equivalent to or lower than noise generated during well design and production life cycle stages.	2 low

[97] Refer to section 1.4.3 on cumulative impacts.

6.6.3 Long-term well integrity

6.6.3.1 Overview

Wells that are abandoned post closure often contain residual hydrocarbons and there is a possibility that over time these can leak from the well bore, if integrity is not ensured. This can lead to the pollution of seawater by hydrocarbon liquids and contributions to greenhouse gas emissions from leaking hydrocarbon gases.

Analyses of 8,000 offshore wells in the Gulf of Mexico showed that 11–12% of wells developed pressure in the outer strings (called 'sustained casing pressure' – implying a failure in one of the barriers) (Bruffato et al, 2003) as did 3.9% of 316,000 wells in Alberta (Watson & Bachu, 2009). However, not all wells with a single barrier failure result in leakage as there can be multiple safety barriers and there must be a pressure or buoyancy gradient for fluids to migrate. King & King (2013) estimate that the probability of full integrity failure resulting in a leak is two or three orders of magnitude lower than a single barrier failure. However, Davies et al (2014) stated that to their knowledge monitoring of abandoned wells does not take place in the UK or any other jurisdiction (e.g. Alberta, Canada) they know of, and less visible pollutants such as methane leaks are unlikely to be reported. It is therefore possible that well integrity failure may be more widespread than the presently limited data show. The impact of this lack of monitoring and the extent to which this may be applicable in other member states is not clear.

Ingraffea et al (2014) found that the risks of integrity failure may be up to 6 times higher for in unconventional wells as compared to conventional wells, which was attributed to the high pressures associated with hydraulic fracturing.

There is limited literature available on methane emissions from abandoned wells, but one study by Kang et al (2014) measured methane fluxes from 19 such wells in Pennsylvania. 3 of these wells were found to be high emitters of methane and as a result they concluded that abandoned wells have the potential to contribute significantly to total global methane emissions, due to the large number of them worldwide.

6.6.3.2 Measures

- Regular pressure monitoring may be carried out to determine well integrity.

As set out in Section 7, where such monitoring is carried out, this is generally done by operators (rather than authorities).

6.6.3.3 Issues

The risk level for topside preparation for removal using hot cutting, welding, etc. is presented in Table 6.38.

Table 6.38: Risk and impacts of long-term well integrity failure

Main Environmental Aspects	Impacts	Risk Level
Discharges to sea – leaked hydrocarbons	Over time, liquid hydrocarbons may penetrate the cement casing and leak from the well bore, resulting in contamination of sea water.	4 Low
Releases to air (contributions to climate change)	Well integrity failure can result in hydrocarbon gases (incl. methane) being released to the atmosphere and contributing to climate change. King & King (2013) found that when a total well-integrity failure occurs, gas is the most common fluid lost.	4 low

7. Measures

7.1 Introduction

Outlined briefly in the previous sections and the risk matrices (appendices A and B), this section examines in more detail the risk mitigation measures which could reduce and, in some cases, eliminate negative impacts to the environment resulting from upstream oil and gas activity. Due to the high level scope of the assessment, it has not been possible to examine mitigation of impacts for each reservoir type, although it is recognised that there is considerable variability in terms of what measures are appropriate in different geographies. Instead, the measures identified in this section apply to areas with typical environmental features for onshore and offshore upstream activities.

For offshore activities, measures based on regulation vary according to the conventions that apply in different regions of European seas. For a description of these conventions, please see Appendix C.

Table 7.1 examines the measures that are commonly adopted (but not necessarily systematically applied by all operators) for both onshore and offshore conventional oil and gas upstream activities. Table 7.2 then lists the exploration and production activities from the risk assessment which may continue to present high levels of risk, even after mitigation measures have been applied to them. A further review was then conducted on additional measures which could be applied to these activities, in order to reduce their risk levels or medium to lower. The review considered current measures with low rates of uptake and emerging measures or technologies which are currently under development and/or only used by a minority of operators. Descriptions of these further measures are provided in section 3 and Appendix A and B. Where further measures not already identified in other parts of the report they are detailed in Table 7.4 below.

7.2 Measures Already in Place

Table 7.1 provides information on the risk management measures that are already commonly used for hydrocarbon exploration and production (but not necessarily systematically used by all operators). Information from other sections of the report was compiled to provide a brief summary of each measure, the benefits it offers and the level of uptake. In a number of cases, measures had applications across several processes, both onshore and offshore. These were aggregated accordingly, to avoid duplication.

Potential uptake rates for measures have been estimated as either 'likely to be applied' or 'possible to be applied' using expert judgement. These qualitative indicators have also been translated to an approximate percentage of uptake (90% and 40% respectively), as per the approach used for shale gas in AMEC (2014). In the 2014 report the costs of implementing risk management measures fed into a quantitative impact assessment; therefore to avoid an overestimation of impacts for those which were not systematically used by all operators, costs were adjusted downward to reflect a (purely hypothetical) level of uptake. Specifically, 10% of compliance costs was assumed for the measures that were considered to be *likely to be applied* (i.e. 90% uptake level) and 60% of costs for the measures considered to be *possible to be applied* (i.e. 40% uptake level). The percentage uptake figures, suggested by the Commission, were therefore only illustrative and were not intended to be predictors of actual uptake of any individual measure by operators. They are used again here but it should be absolutely clear that these are not estimates of actual percentage uptake across the EU; they are purely indicative.

Table 7.1: List of measures assumed to be already in place for offshore and onshore activities.

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Whale Watching	During the exploration phase of offshore oil and gas, seismic equipment is used to gather information about the seabed and seabed geology. The use of seismic equipment in the marine environment poses a threat to aquatic life, particularly cetaceans. This can include disturbance and behaviour effects from low level use of seismicity or at more intense use physical harm caused by seismic waves. Whale watching involves use of surveying the area by eye before the use of seismic equipment to ensure that species likely to be affected are not in the immediate vicinity.	Whale watching is a basic precautionary strategy that works by avoiding the use of seismic equipment at times when vulnerable species are within proximity that seismic equipment may cause harm.	Frequency of potential event reduced	Likely to be applied (90%) (Requirements/guidance under e.g. ASCOBAMS and ACCOBAMS with associated guidance e.g. guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area.)	Offshore
Passive aquatic monitoring sub-sea (PAM)	Alongside the use of whale watching as a visual check to identify cetaceans within the vicinity of seismic surveys for exploration; passive aquatic monitoring is a system used below the surface of the water to monitor for whale sound and detection of cetaceans that may be in the vicinity. The use of whale watching and PAM can be used to fully assess presence of marine mammals before surveying commences.	Along with Whale watching the use of PAM is intended to help operators assess the sea for presence of cetaceans before the seismic surveying begins. PAM adds additional benefits to detecting these species where visual checks may struggle.	Frequency of potential event reduced	Likely to be applied (90%) (Requirements/guidance under e.g. ASCOBAMS and ACCOBAMS with associated guidance e.g. guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area.)	Offshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Soft start for seismic equipment	In addition to Whale Watching and PAM measures to monitor cetacean activity, harm caused by seismic equipment used for exploration may be reduced by operating equipment with a soft start. This refers to the early stages of seismic surveying, where the equipment should begin with low energy pulses building slowly to full operational capacity at the height of surveying.	It is intended that commencing with a soft start is less shocking for marine life within range of the survey area and allows marine species to evade the surveying before it reaches full operational capacity.	Frequency of potential event reduced	Likely to be applied (90%) (Requirements/guidance under e.g. ASCOBAMS and ACCOBAMS with associated guidance e.g. guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area.)	Offshore
BAT technologies for low sulphur fuels in marine shipping, aircraft	Marine shipping is involved in multiple life-cycle stages of the offshore hydrocarbon exploration and production process, including surveying, transporting of the drill rig, drilling and supplying of the platform. Additionally, aircraft are used in the surveying stage of both offshore and onshore activities. BAT (Best Available Technique) technologies and low sulphur fuels may be used in the engines of relevant vessels and aircraft to increase efficiency and reduce emissions of key pollutants such as NOx, SOx and Particulate Matter (PM) in their exhaust stream.	The quantity of pollutants emitted to the atmosphere from shipping and aviation related to offshore and onshore activities are reduced. This in turn reduces contributions to ocean acidification, global warming and eutrophication. It should be noted that some abatement technologies which reduced air pollutants also reduce the efficiency of the engine, thus increasing carbon intensity.	Likely to reduce the consequence of the event, but tangible impact on risk reduction is less clearly demonstrated	Possible to be applied (40%) (All ships in Baltic, N Sea and English Channel SECAs to use <1% S fuel under MARPOL Annex VI; less stringent requirements in other parts of the EU.)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Double hulled vessels for fuel transport	All fuel consumed on an offshore rig must be transported by sea. Vessels that are used for the transportation of this fuel may be fitted with two complete layers of watertight hull surface rather than one. The second forms a redundant barrier to seawater, in case the outer hull is damaged and leaks.	Double hulling provides an additional layer of protection to cargo. This reduces the risk that collision involving a fuel vessel will result in a hydrocarbon spillage and associated damage to marine and shoreline ecosystems.	Consequence of potential event reduced	Possible to be applied (40%) (MARPOL convention has required double hulls in newly built oil tankers since 1992. Use potentially less in offshore support vessels.)	Offshore
Exclusion zones around drilling rig	Where hydrocarbon drilling rigs are in busy construction or shipping areas, exclusion zones may be established surrounding the equipment. Vehicles or vessels and personnel are not permitted to enter these zones unless they are engaging directly with the rig, thus reducing the likelihood of injury or disturbance of the drilling process.	Exclusion zones reduce the risk of collisions between vessels or vehicles and the drilling rig, which could result in a hydrocarbon spillage and associated damage to surrounding ecosystems. They also reduce the risk of personnel being injured by drilling equipment.	Consequence of potential event reduced	Likely to be applied (90%)	Offshore and onshore
Bunding, protected skids, totes	Offshore and onshore sites store large quantities of diesel to generate power. A variety of chemicals and wastes are also stored as part of the hydrocarbon production process. These substances can be held in designated and protected storage areas. Individual containers may also be encased in protective bunding and liquids should be held in totes where relevant, to prevent leakage or inundation.	Protective storage containers and areas reduce the risk of a chemical or hydrocarbon spill by lowering the likelihood of the container being breeched in the event of an accident resulting in impact. This reduces the risk of harm to personnel and pollution of ground or seawater.	Consequence of potential event reduced	Likely to be applied (90%)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Dynamic positioning vessels for drilling	Well drilling for hydrocarbon exploration and production is very sensitive to movement. The rig is therefore often anchored to the seabed using multiple cables, the installation of which causes damage to the seabed habitat. Directional positions (DP) vessels utilise four computer-controlled thrusters around the perimeter of the ship to compensate for the effects of tidal and wind motion. This ensures that the drilling vessel is kept stationary relative to the well, without the need for supportive cabling.	Utilising DP technology eliminates the damage to the seabed habitat that physical securement of the drilling rig causes. However, the increased fuel usage for DP results in additional emissions of greenhouse gases and air quality pollution.	Consequence of potential event reduced	Possible to be applied (40%)	Offshore
Quarantine measures for moving rig to avoid invasive species	Drilling rigs used for offshore exploration and production are often moved large distances during their construction and installation. Platforms which have resided in an ecosystem that is different to the one in their final destination may have acquired resident species on their outer surface. In order to ensure that these are not transferred to the second ecosystem, during transport the rig may be quarantined until it is deemed to be free from species which could be invasive.	The introduction of invasive species can cause significant damage to ecosystems and diminish the important services they provide to mankind. By quarantining rigs that have been moved between marine ecosystems, the likelihood of this occurrence is reduced.	Frequency of potential event reduced	Possible to be applied (40%) (Requirement under BWM Convention for ballast water but not yet entered into force; IOGP/IPIECA 2010 guidelines on AIS and the O&G industry. Extent of uptake unknown.)	Offshore

Title of measure	**Description of measures**	**Benefit**	**Risk management effect**	**Uptake rates**	**Application (onshore/ offshore/both)**
Lifting procedures for heavy equipment	During drilling, loading/unloading and decommissioning of an offshore rig, heavy equipment is frequently employed. The habitat on the seabed is sensitive and impacts from equipment which have been accidentally dropped can cause significant damage. Lifting procedures for heavy equipment may be implemented, so that relevant personnel can follow a standard course of actions when utilising the equipment. This will decrease the chance of accidents occurring.	By implementing procedures for the lifting of heavy equipment, the risk of an accident resulting in an impact on the seabed is minimised.	Likely to reduce the likelihood of the event, but tangible impact on risk reduction is less clearly demonstrated	Likely to be applied (90%)	Offshore
Maintenance programs for all equipment	The hydrocarbon exploration and production lifecycle involves the use of many pieces of complex equipment, including: cranes and lifting equipment, drilling machinery, combustion engines, pumping equipment and pipelines. Frequent maintenance sessions may be performed on all equipment as part of an organised program, to check for faults and ensure that they are fit for purpose on a regular basis.	The implementation of maintenance programs ensures that equipment is fit for purpose and reduces the risk of important equipment failures, which can cause a multitude of negative effects.	Frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Use of low hazard/risk chemicals and avoided use of high risk chemicals	Chemicals are used in several stages of the exploration and production lifecycle. Accidental (or planned) discharge of these substances to the ocean or ground is likely, particularly those which are injected into the well such as completion fluid or surfactants. Through regulation, the use of low hazard chemicals can be promoted and the use of high hazard chemicals prohibited or limited. For example, the OSPAR list of substances that 'Pose little or no risk' to the environment (PLONOR) (OSPAR, 2012b) or under the "zero discharge principle" for the HELCOM region which requires cessation of discharges of all "black" and "red" listed chemicals under the Baltic Sea Action Plan. Under the Barcelona Convention, discharge of harmful or noxious substances is either prohibited (Annex I) or requires a permit (Annex II); development of guidelines specifying the limitations or prohibitions for use of chemicals has been recommended. The REACH and CLP Regulations will also significantly affect choice/use of chemicals across Europe. However, there remain differences	The use of low hazard/risk chemicals and avoided use of high hazard/risk chemicals reduces the environmental damage caused by the accidental discharge to seawater or ground of chemicals used in the exploration and production process.	Consequence of potential event reduced	Likely to be applied (90%)	Offshore and onshore

Title of measure	**Description of measures**	**Benefit**	**Risk management effect**	**Uptake rates**	**Application (onshore/ offshore/both)**
	in approach amongst Member States in terms of chemical selection/substitution (Chemical Watch, 2014).				
Blow-out preventer	Subterranean hydrocarbon fields are held under high pressure by forces in the earth's crust. When these fields are penetrated by a well, the force must be controlled to ensure that well fluids are contained during production. A blow-out preventer is a piece of equipment which acts as an emergency system to ensure that in the event of a failure of primary well control systems, over pressurisation does not result in a loss of containment of well fluids (a 'blowout').	A blowout can cause devastating environmental damage, as huge quantities of hydrocarbons are leaked into the surrounding ecosystems. A blow-out preventer prevents a loss of well fluids, should the primary well control systems fail.	Consequence and frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore
Valve systems (SSIVs, X-mas trees, choke and kill):	Offshore and onshore rigs use many pipelines to transport chemicals and hydrocarbons. If these become damage, the fluids may be lost either to the surrounding ocean or to ground and groundwater, resulting in ecological harm. Valve systems such as subsea isolation valves (SSIV), Christmas tree values and choke and kills values can be used to shut off sections of piping. This ensures that if a pipeline is ruptured or	Valve systems in piping reduce the quantity of fluids leaked to the surroundings in the event of a leakage or rupture. This reduces the pollution of land, groundwater and sea caused by such an event.	Consequence and frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
	leaking, the spillage can be contained.				
Well pressure monitoring	Alongside the use of a blow-out preventer to contain well fluids in the event of a loss of pressure control, monitoring technology may be employed to keep track of pressure within the well. This record of well pressure can be viewed in real-time, to enable personnel to take appropriate precautions to reduce well pressure when it is deemed to be dangerous.	Well pressure monitoring systems allow operators to be aware of when well pressure is at dangerous levels and take actions to reduce the risk of a blow-out or leakage, which cause significant environmental damage.	Frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore
Emergency plans	Alongside the use of other measures to control accidental chemical or hydrocarbon releases, emergency plans may be put in place for personnel operating on the hydrocarbon site. These plans cover the clean-up procedures to take in the event of a spill. For more extreme spills (Tier III) they can also include plans for oil spill modelling, the training of specialist spill response operators and the contracting of assistance from specialist oil spill contractors.	Emergency plans allow personnel to be prepared to cope with chemical or oil spills when they occur. This ensures that clean up procedures are followed promptly and efficiently, and environmental damage from the spill is minimised.	Consequence of potential event reduced	Likely to be applied (90%)	Offshore and onshore
Quick release valves for fuel off-take	Decanting and hose operations are used for the offtake of fuel and other fluids from storage tanks on the hydrocarbon site. Quick release	Quick release valves reduce the amount of fluid spilt during off-take. This decreases the environmental	Consequence of potential event reduced	Possible to be applied (40%)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
	valves may be fitted to the tanks. These allow pipelines or hoses to be remotely detach once transfer is complete, thus reducing the chance of a spillage of excess fluid.	damage caused by spills.			
Flare tip design (enclosed flares) for gas flaring	In order to reduce air quality impacts and greenhouse gas emissions from gas released by a hydrocarbon field that cannot be processed, a proportion is continuously combusted in either an open air or enclosed system, known as flaring. Generally, open flares are inexpensive and relatively simple, but achieve poor emissions compared to enclosed flares, due to their lower combustion temperatures and shorter residence times. However, there are site specific factors (composition of hydrocarbon gas, noise considerations, etc.) which determine whether an open or enclosed flare is more suitable (Enggcyclopedia, n.d.). Flaring is also used as a safety precaution to control pressure build ups from gas in the well. BAT (best available techniques) may be used for the flare tip design. This ensure that the efficiency of the combustion is as high as possible and reduces the	Implementing BAT technology for flare tip design reduces the amount of air pollutants and CO_2 emitted to the atmosphere from gas flaring.	Consequence and frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore

Title of measure	**Description of measures**	**Benefit**	**Risk management effect**	**Uptake rates**	**Application (onshore/ offshore/both)**
	emissions to air of pollutants such as NOx and smoke to the lowest levels that current technology allows.				
Light management on rig (shielding, adjusted wavelength, flashing cycle	During piling for jacket foundations and/or mooring line anchors to support an offshore rig, large amounts of lighting are used to aid the drilling vessel. As the hydrocarbon production process is continuous, night-time lighting is also regularly used on the rig. These light sources can cause significant harm to birdlife, particularly stalks, by disturbing their navigation. Light management techniques may be employed to reduce excess lighting. These include shielding light sources, adjusting the wavelength of light to that which is less receptive to birds and using a flashing light cycle to reduce the quantity of light emitted.	Implementing light management techniques reduce the amount of birdlife that is killed as a result of lighting on an offshore rig interfering with their navigation.	Consequence of potential event reduced	Possible to be applied (40%)	Offshore
Controlled fall-pipe for rock dumping	Rock dumping refers to the use of rocks either to secure offshore hydrocarbon platforms to the seabed or as part of the decommissioning procedure for an onshore or offshore site. Specially designed vessels or vehicles may be used to carry out the rock dumping, which are fitted with	The use of controlled fall-pipes reduces the harm caused to surrounding habitats by the rock dumping process by ensuring that it is carried out accurately.	Likely to reduce the consequence of the event, but tangible impact on risk reduction is less clearly demonstrated	Possible to be applied (40%)	Offshore and onshore

Title of measure	**Description of measures**	**Benefit**	**Risk management effect**	**Uptake rates**	**Application (onshore/ offshore/both)**
	controlled fall-pipes. These allow the rocks to be guided to where they are needed, reducing the vibrations and damage caused by the process to surrounding habitats.				
Planning and design of sub-sea infrastructure	Underwater noise and the long term physical presence of an offshore rig on the seabed can cause damage to marine creatures and habitats. The sub-sea infrastructure of the rig may be designed and construction activities carefully planned to ensure that sub-sea physical presence and disturbance is minimised.	By planning and designing sub-sea infrastructure, the disturbance caused by the rig on the seabed can be minimised. This reduces the damage to seabed habitats.	Frequency of potential event reduced	Likely to be applied (90%)	Offshore
Leak detection and repair programmes	During the production, processing and handling of natural gas, accidental emissions to the atmosphere may occur. Methane and other trace chemicals in natural gas contribute to climate change and deteriorate air quality. Leak detection systems, combined with trained repair personnel and equipment can be used to reduce the amount of gas lost due to leakage.	Implementing leak detection systems and repair programmes reduces the amount of natural gas lost to leakage. This reduces contributions to climate change and air pollution.	Frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Process design to avoid for gas venting in production	During natural gas production, gas may be vented in either a planned manner as part of the process, or an unplanned manner to control pressure for safety reasons. The production process can be designed by engineers to minimise the need for gas venting, either planned or unplanned.	Efficient process design of the natural gas production process reduces the amount of natural gas vented to the atmosphere and hence reduces harmful contributions to local air quality and climate change.	Frequency of potential event reduced	Likely to be applied (90%)	Offshore and onshore
Treatment and analysis of discharged water	Sand and water are often produced from a hydrocarbon well alongside oil and gas. These contain residual hydrocarbons, production chemicals and reservoir contaminants. Systems may be installed to analyse and monitor the amount of pollutants in produced water (PW), and it may be treated before it is discharged in order to reduce the amount of contaminants it contains.	The treatment and analysis of water produced from the well reduces the amount of oil and other harmful pollutants emitted to surrounding ecosystems when the water is discharged.	Consequence of potential event reduced	Likely to be applied (90%) (Requirements under international conventions for oil in PW e.g. 30 mg/l under OSPAR, 15 mg/l under HELCOM, 40 mg/l under Barcelona Convention.)	Offshore and onshore
Design and management of systems for cooling to limit thermal effects	Offshore hydrocarbon rigs use open loop seawater cooling for their process and utility systems. This results in the emission of thermal pollution when the water is returned to the sea. Thermal pollution damages local ecosystems by altering the ambient conditions that species are adapted to.	Implementing this measure will reduce emissions of thermal pollution from an offshore platforms cooling processes to the sea, which harms marine ecosystems.	Frequency of potential event reduced	Likely to be applied (90%)	Offshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
	Production processes may be designed and managed to minimise the need for cooling and hence the emissions of thermal pollution to the ocean.				
Design and management of systems for cooling	Onshore production processes commonly utilise HVAC systems that contain ozone depleting substances (ODS). Accidental release of these substances contributes to climate change. Production processes may be designed and managed carefully to minimise the need for cooling, thus reducing the risk of an escape of ODS to the atmosphere.	Careful design and management of systems for cooling in onshore hydrocarbon production and exploration reduce the chance that ODS are emitted to the atmosphere, which contribute to global warming.			Onshore
Ongoing monitoring of site post closure for issues	After hydrocarbon production is no longer economically viable, a site is decommissioned. Discarded drill cuttings and other remnants are piled up and the well bore is sealed. The presence of the pile can interfere with local habitats and leachate from the cuttings may cause pollution. Additionally, the wellbore can leak. The wellbore and pile can be monitored	By implementing ongoing monitoring of hydrocarbon production and exploration sites post closure, operators are able to intervene to address high levels of pollution or habitat damaged that may be being caused by the site remnants.	Likely to reduce the consequence of the event, but tangible impact on risk reduction is less clearly demonstrated	Possible to be applied (40%)[98]	Offshore and onshore

[98] Based on the findings in Davies et al (2014) that to the best of their knowledge, post-closure monitoring is not carried out at all the UK, this may be an overestimate. However, there are several industry guidance documents which make reference to post-closure monitoring including OGP (1997), IGEM (2013) and IFC (2007). Additionally, the scope of the findings in the Davies et al (2014) study are limited relevant to this report, because they refer to only one jurisdiction within the EU. On this basis, the judgement that the measure is 'possible be applied (40%)' has been maintained.

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
	periodically after the site closure to ensure that pollution levels and habitat damage are not high enough to require further intervention.				
Environmental planning for geophysical testing	Geophysical testing and seismic surveys are used frequently in the onshore exploration process, to analyse rock formations and identify potential hydrocarbon reserves. Environmental planning may be carried out prior to conducting these surveys, so that tests are adapted to account for seasonality of migrating birds and fauna breeding seasons, which may be disturbed by seismic activities.	Environmental planning during the geophysical testing phase of hydrocarbon exploration reduces the disturbance caused to fauna and birdlife by onshore seismic activities by ensuring that surveys are not conducted during breeding or migration seasons.	Frequency of potential event reduced	Possible to be applied (40%)	Onshore
BAT seismic equipment	Seismic equipment is used in the surveying stage of offshore and onshore hydrocarbon exploration. BAT (Best Available Technique) seismic technologies may be used to carry out geophysical testing. This ensures that the intrusion of seismic practices on local ecosystems is kept to the lowest levels achievable by current technologies.	Using BAT seismic equipment in the surveying phase of hydrocarbon exploration ensure that the disturbances to wildlife caused by geophysical testing are as low as technologically possible.	Likely to reduce the consequence of the event, but tangible impact on risk reduction is less clearly demonstrated	Possible to be applied (40%) (Guidance exists e.g. in Norway under NOROG, in UK under JNCC; plan needs development for specific prevention measures for noise from seismic surveys under Barcelona Convention)	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Environmental planning	Environmental planning involves careful consideration of the environmental impacts of activities, so that they may be minimised. This includes planning transportation routes, utilising good construction practices, implementing a waste management plan, minimising landtake of sites and establishing of baseline environmental aspect conditions which can be used to review potential impact on environment. Many stages of the onshore exploration and production lifecycle can be subjected to environmental planning, including: the mobilisation of drill rig and equipment, well rig construction, drilling of the well and decommissioning of the site.	Comprehensive environmental planning ensures that the environmental damage caused by many stages of the onshore exploration and production lifecycle are controlled and minimised where possible.	Consequence and frequency of potential event reduced	Likely to be applied (90%)	onshore
Noise abatement measures	The equipment used to drill hydrocarbon wells generates high levels of noise during operation. This noise can disturb wildlife and humans in the vicinity of the drill site. Screening, known as noise barriers or sound walls, may be installed around the drill. These are made of absorptive material that mitigates the intensity of the sound, thus reducing the harm that it causes to nearby creatures.	Noise abatement measures such as sound walls mitigate the intensity of sound emitted from hydrocarbon well drilling equipment. This reduces the disturbance caused to humans and wildlife in the vicinity of the site by drilling.	Frequency of potential event reduced	Possible to be applied (40%)	onshore

Title of measure	Description of measures	Benefit	Risk management effect	Uptake rates	Application (onshore/ offshore/both)
Water resource planning	Enhanced recovery activities such as water flooding and water and gas injection can use large quantities of water. To minimise the impact this can have on the environment, careful planning can be undertaken to ensure water is not taken from areas or sources that are prone to depletion and impose time restrictions on surface water diversions.	The water injected into hydrocarbon wells is removed from the water cycle for a considerable period of time, which has the potential to result in a strain on local freshwater resources. Through careful planning, the risk of water depletion and its associated negative impacts on the environment can be reduced or avoided.	Frequency of potential event reduce	Possible to be applied (40%)	onshore

Information on onshore specific measures was derived from best practice onshore guidance produced by the Energy and Biodiversity Initiative (EBI, 2003). EBI is a partnership of oil and gas companies such as BP and Shell together with conservation organisations, designed to promote biodiversity conservation practices in upstream activities. The list covers all aspects of the upstream exploration and production lifecycle that impact biodiversity. It was compiled with stakeholders from industry and is thus considered as comprehensive as possible, although it is acknowledged that best practices are constantly evolving and are also to some extent site-specific. The list covers practices that are generally applied by industry and have been shown to be effective when used appropriately. However, they are not necessarily applied systematically by all operators.

7.3 Further Measures to Address Remaining Risks

Following the consideration of existing measures, several processes in the exploration and production lifecycle continued to pose a relatively high level of environmental risk. This does not imply that no additional measures are being applied to address these environmental risks in practice, but simply that there may be examples of installations where further measures would enable a further reduction in environmental risks.

Table 7.2, Table 7.3 and Table 7.4 highlight these processes and identify further measures for risk management. These are comprised of emerging technologies/processes thought to be used only/mainly by top performers, existing measures with relatively low uptake that are not yet applied systematically by operators and measures applied in other stages of exploration and production. Further measures were then assessed for their feasibility and effectiveness to mitigate risk, based on levels of technological development and potential impact.

Table7.2: List of remaining high risk processes and relevant further measures for offshore activities.

Process	**Environmental Aspect**	**Impact**	**Residual risk level (9+)**	**Further measures**	**Feasibility** [99]	**Effectiveness**
2. Well design and construction and well completion						
Transport of drilling rig and well drilling						
Drilling using water based muds (WBM)/oil based muds (OBM)	Releases to water: Accidental hydrocarbon spill – Tier III (requiring assistance from third party resources)	Marine biodiversity/ habitat loss	Risk: 12 (High)	**Measurement While Drilling (MWD)** systems	Proven Feasibility	Moderate potential for additional risk management
		Coastal biodiversity/ habitat loss	Risk: 15 (Very High)			
		Deterioration in water quality	Risk: 9 (High)			
	Releases to water: Accidental hydrocarbon spill - Tier II (requiring assistance from other Operator	Marine biodiversity/ habitat loss	Risk: 9 (High)			
		Coastal biodiversity/ habitat loss	Risk: 12 (High)			

[99] Measures are considered to have 'proven feasibility' if they are developed, tested and applied, and 'unproven feasibility' if they are not developed and tested.

Process	Environmental Aspect	Impact	Residual risk level (9+)	Further measures	Feasibility [99]	Effectiveness
	resources)	Sediment fouling/ smothering of benthic flora and fauna	Risk: 9 (High)			
			3. Production			
			Platform installation – floating, fixed			
Rock dumping	Seabed disturbance due to rock dumping	Sediment fouling/ smothering of benthic flora and fauna	Risk: 9 (High)	Increase uptake of **Controlled Fall-pipe Vessels**	Proven Feasibility	High potential for additional risk management
Installation of sea-bed production infrastructure	Seabed disturbance: Installation of subsea equipment	Sediment fouling/ smothering of benthic flora and fauna	Risk: 12 (High)	**Semi-Autonomous Robotics** systems	Proven Feasibility	Moderate potential for additional risk management
Subsea production system	Physical presence: Long term habitat loss from presence on Seabed	Sediment fouling/ smothering of benthic flora and fauna	Risk: 10 (High)	None identified	-	-
Gas production, processing and handling	Releases to air: Planned gas emissions	Contribution to global emissions	Risk: 9 (High)	None identified	-	-
Off-gas management – flaring	Releases to air: Planned flaring of off-gas for production	Contribution to global emissions	Risk: 12 (High)			

Process	**Environmental Aspect**	**Impact**	**Residual risk level (9+)**	**Further measures**	**Feasibility** [99]	**Effectiveness**
4. Project cessation and well closure						
Well closure						
Well P&A conductor recovery	Seabed disturbance from the drill cuttings pile, if present	Potential release of toxic contaminants into the water column and seabed, which may impact pelagic and demersal species	Risk: 12 (high)	**Slimhole drilling** to reduce the quantity of cuttings produced	Proven Feasibility	Low potential for additional risk management
Management of cuttings pile						
Leave *in situ* with no removal or disturbance	Long-term pile presence and contaminant persistence	Continued impact on sediment quality and benthic communities from an undisturbed cuttings pile.	Risk: 10 (High)	**Slimhole drilling** to reduce the quantity of cuttings produced **Bioremediation**	**Slimhole drilling:** Proven Feasibility **Bioremediation:** Proven Feasibility	**Slimhole drilling:** Moderate potential for additional risk management **Bioremediation:** Moderate potential for additional risk management
Excavation of the pile and recovery to surface	Seabed Disturbance: physical disturbance to the drill cuttings pile potentially releasing toxic contaminants to the water column and seabed	Toxic contaminants may impact pelagic and demersal species. Deposition of cuttings impacting benthic communities.	Risk: 12 (high)			
Excavation of the drill cuttings pile and redistribution to another area of	Seabed disturbance to the drill cuttings pile potentially releasing toxic	Toxic contaminants may impact pelagic and demersal species.	Risk: 12 (high)			

Process	Environmental Aspect	Impact	Residual risk level (9+)	Further measures	Feasibility [99]	Effectiveness
seabed	contaminants to the water column and seabed	Deposition of cuttings impacting benthic communities.				
5. Post closure and abandonment						
Jacket decommissioning						
Physical presence of jacket footings left *in situ*.	Commercial consequences of snagging fishing gear	-	Risk: 12 (high)	None identified	-	-
Pipeline and bundles decommissioning						
Leave pipeline/sections in place - Rock placement	Physical disturbance causing suspension of material	Physical disturbance to seabed and suspension of sediment into the water column.	Likelihood: Occasional Consequence: Moderate Risk: 9 (high)	See Rock Dumping	-	-

Table 7.3: List of remaining high risk processes and relevant further measures for onshore activities.

Process	**Environmental Aspect**	**Impact**	**Residual risk level (9+)**	**Further measures**	**Feasibility** [100]	**Effectiveness**
Stage 3 Development and production						
8. Construction and installation						
8.1 Implementation of development plan	Land and vegetation clearing, excavation	Increased land clearance leading to further loss of vegetation and land for flora and fauna. Habitats destroyed.	Risk: 12 (high)	**Coiled Tubing Drilling**	Proven Feasibility	Moderate potential for additional risk management
				Closed Loop Drilling	Proven Feasibility	High potential for additional risk management
				Slimhole Drilling	Proven Feasibility	Low potential for additional risk management
10. Development drilling						
10.1 Development drilling	Removal of vegetation and loss of land to access road, construction area, storage area. Industrialised area. Conventional oil and gas drilling	Visual impact disturbance on local residents and wildlife due to the strong lights at night.	**Risk: 15 (very high)**	**Light Management Techniques** used in offshore drilling	Proven Feasibility	High potential for additional risk management

[100] Measures are considered to have 'proven feasibility' if they are developed, tested and applied, and 'unproven feasibility' if they are not developed and tested.

Process	Environmental Aspect	Impact	Residual risk level (9+)	Further measures	Feasibility [100]	Effectiveness
	typically require 1 well per pad. Situated in areas with high value or near residential areas.	Increased land clearance leading to further loss of vegetation and land for flora and fauna. Habitats destroyed.	**Risk: 10 (high)**	Greater uptake of measures from 8.1 Implementation of development plan, including: minimisation of land take and use of existing routes for access.	-	-

A brief summary of each further measure and their benefits are summarised in Table 7.4. For measures which have previously been discussed in the report, the table refers to the appropriate section in order to avoid duplication.

Table 7.4: Description of relevant further measures for onshore and offshore activities.

Title of measure	Description of measures	Benefit	Risk management effect	Application (onshore/ offshore/both)
Measurement While Drilling (MWD)	MWD systems allow for the collection of data from the bottom of a well as it is being drilled, via sensors connected to the drill head.	MWD improves drilling efficiency and accuracy in the drilling process, allows better formation evaluation as the drill bit encounters the underground formation, and reduces the chance of formation damage and blowouts (Rigzone, 2015)	Frequency of potential event reduced	Offshore and onshore
Robotics	See section 2.4.4	Robotics systems may be used to conduct installations on the sea bed. This increases engineering precision, thereby reducing damage caused to the seabed habitat.	Consequence of potential event reduced	Offshore
Floating Liquefied Natural Gas (FLNG)	FLNG operations use cutting-edge technology to pressurise gas extracted offshore into a liquid state,	FLNG allows natural gas to collect from wells which cannot feasibly be reached by pipelines, reducing the need	Frequency and consequence of potential event reduced	Offshore

Title of measure	Description of measures	Benefit	Risk management effect	Application (onshore/ offshore/both)
	significantly reducing the volume required for storage. The LNG is then stored in floating container, because it is less dense than water (KPMG, 2014).	for flaring and therefore contributions to global emissions and climate change. The risk of harm to humans resulting from accidents during liquefaction of gas is also reduced, as the process occurs offshore rather than onshore.		
Controlled fall-pipe vessel	See Appendix B	-	-	-
Slimhole Drilling	This measure involves drilling a narrower well, typically less than 6 inches in diameter. This can only be achieved by state of the art drilling equipment (Naturalgas.org, 2013)	This greatly reduces the amount of drill cuttings that are produced, reducing the damage they cause when they are stored.	Consequence of potential event reduced	Offshore and onshore
Bio-remediation	Bio-remediation involves introduces micro-organisms to the cuttings pile. These micro-organisms digest organic substances that are left in the mud residue on the drill cuttings (DWM, 2015)	Organisms breakdown harmful pollutants that leach from the pile and cause harm to the surrounding ecosystems.	Consequence of potential event reduced	Offshore
Coiled Tubing	Coiled Tubing technologies replace the traditional rigid, jointed drill pipe with a flexible coiled pipe string.	This provides a smaller drilling footprint, requiring less mud, taking less time to start-up and occupying less space than a traditional drill pipe. This reduces the impact of the rig on the local habitat (Naturalgas.org, 2013).	Consequence of potential event reduced	Offshore and onshore

Title of measure	Description of measures	Benefit	Risk management effect	Application (onshore/ offshore/both)
Closed loop drilling	Closed loop drilling technologies recycling and clean mud in a closed system, rather than requiring a mud-pit where used mud is stored before processing (Earthworks, 2015).	Closed loop drilling reduces the land take of operations, the risk of ground water and land pollution and decreases the amount of mud waste. This reduces the amount of pollution emitted and damage caused to surrounding habitats.	Consequence of potential event reduced	Offshore and onshore
Light management techniques	See Appendix B	Light management reduces the harm caused to wildlife by the lighting used to carry out night-time drilling	Consequence of potential event reduced	Offshore and onshore

8. Risk comparison of hydraulic fracturing and enhanced recovery techniques in conventional and unconventional onshore wells

8.1 Introduction

This section compares the risks and impacts of hydraulic fracturing used in low volumes in 'conventional' wells as a well stimulation technique, as well as enhanced recovery techniques with to high volume hydraulic fracturing used in unconventional wells.

As mentioned previously, the distinction between 'conventional' and 'unconventional' fossil fuel extraction is somewhat arbitrary, but is relevant particularly in the context of the thresholds set out in the Commission's 2014 Recommendation 2014/70/EU on hydrocarbons exploration and production using high volume hydraulic fracturing

As well as being used in unconventional extraction, hydraulic fracturing may also be applied for conventional extraction. The fracturing operation in conventional wells is generally expected to use less water than in in unconventional extraction. As discussed in Amec Foster Wheeler (2015a), UFFs tend to utilise more horizontal wells than CFFs. Gallegos et al. (2015) reports that median annual volumes of 15,275 and 19,475m^3 of water per well were used to fracture horizontal oil and gas wells respectively (based on experience from the USA). In other sources, hydraulic fracturing water use estimates range from 1,400 to 33,900 m^3 per shale-gas well [Clark et al., 2013; Goodwin et al., 2014; Nicot and Scanlon, 2012; Scanlon et al., 2014; Kondash & Vengosh, 2015] and 1,300 – 15,000 m^3 per well completed in tight-oil formations [Horner et al., 2014; Scanlon et al., 2014; Kondash & Vengosh, 2015] (based on experience from the USA). In contrast, in Gallegos et al. (2015) it was found that vertical and directional wells typically required less than 2600m^3 of water per well for tight oil extraction in the USA. Variations in the volumes of fluid required for fracturing reflect geological differences across different plays.

This section compares the environmental risks of hydraulic fracturing in conventional wells identified in this report to the environmental risks of hydraulic fracturing in unconventional wells identified in AEA (2012), AMEC (2014) and Amec Foster Wheeler (2015a). Reasons for the differences and similarities between these risks are then considered in light of the fact that fracturing operations in unconventional extraction are larger than those in conventional extraction.

The risks of using enhanced recovery techniques in conventional wells are also compared to the risks of using high volume hydraulic fracturing in unconventional wells, in order to identify differences and similarities between the two processes.

8.2 Approach

In Amec Foster Wheeler (2015a), AMEC (2014) and AEA (2012) the risks associated with each sub-stage of unconventional extraction (for shale gas, tight gas and tight oil) are classified under the same 8 environmental aspects used for onshore activities in this report: ground water contamination, surface water contamination, releases to air, water resource depletion, traffic, land take, noise, visual impact and seismicity.

The risks for each of these environmental aspects in the substage 'technical hydraulic fracturing' in the previous reports were compared to the risks for the substage 'well stimulation – low volume hydraulic fracturing' in this report. The ones which were deemed to vary were taken forward and the reasons for the variation discussed.

The lifecycle sub-stages entitled ‘enhanced recovery’ in this report (water flooding and substance injection - miscible gas / polymer / steam) were also screened to see how the risks and impacts of such processes compared to the risks and impacts associated with high volume hydraulic fracturing used in unconventional wells.

8.3 Comparison – hydraulic fracturing in conventional and unconventional wells

The following hazards and risks were identified for the use of hydraulic fracturing onshore **with measures applied**. Risk ratings for shale gas, tight gas and tight oil are taken from Amec Foster Wheeler (2015a). Risk ratings for conventional extraction are taken from this report. The reasons for the variances or similarities in risk are discussed.

Table 8.1: Comparison of risks between high and low volume fracturing onshore

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Shale gas HF (consequence, likelihood and overall risk)	Tight gas HF (consequence, likelihood and overall risk)	Tight oil HF (consequence, likelihood and overall risk)	Scales with size of operation?	Reason for variance
Technical hydraulic fracturing / well stimulation (low volume hydraulic fracturing)	Ground water contamination	Moderate Rare Moderate 6	Moderate Rare Moderate 6	Moderate Rare Moderate 6	Moderate Rare Moderate 6	N	Measures assumed to be applied reduce the likelihood of ground water contamination to the same level for both conventionals and unconventionals. The consequence of the event is not concluded to scale significantly with the size of the fracturing operation, because even though the scale of the contamination may be physically smaller for low volume fracturing, it still falls into the same category of the risk matrix.
	Surface water contamination	Minor rare low 4 (mitigated) Minor Occasional Moderate 6 (unmitigated)	Moderate Occasional high 9 (unmitigated, from AEA (2012))	Moderate Occasional high 9 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Moderate Occasional high 9 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Y	This aspect is not categorised with measures in place in the Amec Foster Wheeler (2015a) report, therefore only unmitigated risk from AEA (2012) for shale gas is included. Unmitigated risk has been quoted for conventional fracturing from this report, to facilitate a comparison. On this basis, it is assumed that risks will also be higher for HVHF than low volume fracturing, with measures in place. The consequence of the risk is lower for low volume fracturing operations because

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Shale gas HF (consequence, likelihood and overall risk)	Tight gas HF (consequence, likelihood and overall risk)	Tight oil HF (consequence, likelihood and overall risk)	Scales with size of operation?	Reason for variance
							there is significantly less fluids stored above ground. The likelihood of the event does not change as measures assumed to be applied reduce it to the same level.
	Releases to air	Slight Likely Low 4	Slight Likely Low 4	Slight Likely Low 4	Slight Likely Low 4	N	No change. Emissions do not scale significantly with the size of the operation as a significant amount of power generation is needed for all fracturing. It is not clear how the risks of fugitive hydrocarbon gas emissions vary across the different techniques, although information suggests some increase in risks for wells with fracturing versus those without.
	Water resource depletion	Slight Rare Low 2	Low (likelihood and consequence not specified)	Minor Rare Low 4	Minor Rare Low 4	Y	High volume fracturing uses significantly more water than low volume, therefore the consequence of this event is reduced for low volume fracturing. According to Amec Foster Wheeler (2015a), the risk of this aspect is potentially lower for tight oil and gas than shale gas, as they use less water

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Shale gas HF (consequence, likelihood and overall risk)	Tight gas HF (consequence, likelihood and overall risk)	Tight oil HF (consequence, likelihood and overall risk)	Scales with size of operation?	Reason for variance
	Traffic	Minor Rare Low 4	Moderate (likelihood and consequence not specified with measures in place)	Minor Occasional Moderate 6	Minor Occasional Moderate 6	Y	The amount of traffic required for operations is proportional to the amount of flowback, chemicals and water transported. Therefore the consequence of this aspect scales with the size of the fracturing operation.
	Land take	Minor Occasional moderate 6	Minor likely moderate 8	Minor likely moderate 8	Minor likely moderate 8	Y	This aspect is compared to the landtake aspect in stage 1 'well pad site identification and preparation' for unconventionals. The amount of space required for operations is related to the amount of flowback, chemicals and water stored and equipment required. Therefore the consequence of this aspect scales with the size of the fracturing operation.
	Noise	Slight Occasional Low 4 (mitigated) Minor Occasional	Minor Occasional Moderate 6 (unmitigated, from AEA (2012))	Minor Occasional Moderate 6 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler	Minor Occasional Moderate 6 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler	N	This aspect is not included with measures applied in the 2015 report. It is not expected to change significantly once measures are applied, as all fracturing operations produce sound due to the equipment used.

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Shale gas HF (consequence, likelihood and overall risk)	Tight gas HF (consequence, likelihood and overall risk)	Tight oil HF (consequence, likelihood and overall risk)	Scales with size of operation?	Reason for variance
		Moderate 6 (unmitigated)		(2015a))	(2015a))		
	Visual impact	Slight Rare Low 2 (mitigated) Slight Rare Low 2 (unmitigated)	Slight Likely Low 4 (unmitigated, from AEA (2012))	Slight Likely Low 4 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Slight Likely Low 4 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Y	This aspect is not included with measures applied in the 2015 report. AEA (2012) suggests the risk is slightly higher for unconventionals than conventionals. This is unmitigated risk, but measures are unlikely to have a significant effect on this aspect, therefore this aspect may be considered to scale with the size of the fracturing operation. This is due to the higher density of well pads for fracturing operations in unconventional wells.
	Seismic	Slight Rare Low 2 (mitigated) Slight Rare Low 2	Slight Rare Low 2 (unmitigated, from AEA (2012))	Slight Rare Low 2 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Slight Rare Low 2 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	N	The AEA (2012) report quotes unmitigated risk for this aspect as 'low 2' for unconventionals. Therefore it appears that measures do not have a significant effect on this aspect and it does not scale with size of operations. This is because the scale of fracturing activities do not vary significantly enough to change the risk of induced seismicity.

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Shale gas HF (consequence, likelihood and overall risk)	Tight gas HF (consequence, likelihood and overall risk)	Tight oil HF (consequence, likelihood and overall risk)	Scales with size of operation?	Reason for variance
		(unmitigated)					

Based on the comparison the following risks and impacts were found to scale with the size of the fracturing operation:

- Land take;
- Traffic;
- Surface water contamination;
- Water resource depletion; and
- Visual impact.

The values of risk attached to these aspects for different scales of fracturing are approximately only. They are estimates in relation to the parameters that define each well type and are not universally applicable, as each fracturing operation has varying levels of risk based on numerous factors which are not captured in this evaluation. Furthermore, it has not been feasible within the current study to compare the cumulative impacts of multiple conventional wells/pads within a concession, compared to those for unconventional gas installations.

8.4 Comparison – enhanced recovery techniques in conventional wells and hydraulic fracturing in unconventional wells

The following hazards and risks were identified for the use of enhanced recovery techniques onshore **with measures applied**. Risk ratings for hydraulic fracturing used in shale gas, tight gas and tight oil are taken from Amec Foster Wheeler (2015a). Risk ratings for enhanced recovery methods are taken from this report. The reasons for the variances or similarities in risk are discussed. The risks of fracturing in unconventional wells are also included in Table 8.2 in blue, but the differences / similarities for this technique are not discussed as they have already been covered in Table 8.1.

n/a = not applicable.

Table 8.2: Comparison of risks between enhanced recovery techniques and hydraulic fracturing onshore.

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Conventional – water flooding (consequence, likelihood and overall risk)	Conventional – substance injection (consequence, likelihood and overall risk)	HF - shale gas (consequence, likelihood and overall risk)	HF - tight gas (consequence, likelihood and overall risk)	HF - tight oil (consequence, likelihood and overall risk)	Reason for variance
Technical hydraulic fracturing / enhanced recovery (water flooding and substance injection) / low volume hydraulic fracturing	Ground water contamination	Moderate Rare Moderate 6	n/a	Moderate Rare Moderate 6	Moderate Rare Moderate 6	Moderate Rare Moderate 6	Moderate Rare Moderate 6	Groundwater contamination is not relevant for water flooding, because only pure water is used. Measures assumed to be applied reduce the likelihood of ground water contamination to a comparable level for both enhanced recovery (substance injection) and HVHF in unconventionals. This is because both processes involve storing and injecting large quantities of chemicals, which have the potential to penetrate groundwater, therefore the risks are comparable.
	Surface water contamination	Minor rare low 4 (mitigated) Minor Occasional Moderate 6 (unmitigated)	n/a	Moderate Rare Moderate 6 (mitigated) Moderate Occasional High 9 (unmitigated)	Moderate Occasional high 9 (unmitigated, from AEA (2012))	Moderate Occasional high 9 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Moderate Occasional high 9 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	This aspect is not categorised with measures in place in the Amec Foster Wheeler (2015a) report, therefore only unmitigated risk from AEA (2012) for UFFs is included. Unmitigated risk has been quoted for enhanced recovery from this report, to facilitate a comparison. Surface water contamination is not relevant to water flooding, as only pure water is used. For substance injection and unconventional HF, large quantities of chemicals are stored above ground, therefore the risks of a contamination

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Conventional – water flooding (consequence, likelihood and overall risk)	Conventional – substance injection (consequence, likelihood and overall risk)	HF - shale gas (consequence, likelihood and overall risk)	HF - tight gas (consequence, likelihood and overall risk)	HF - tight oil (consequence, likelihood and overall risk)	Reason for variance
								of surface water are similar for these two processes.
	Releases to air	Slight Likely Low 4	Slight Likely Low 4	Slight Likely Low 4	Slight Likely Low 4	Slight Likely Low 4	Slight Likely Low 4	The mitigated risk of air emissions from all processes are similar. This is because a significant amount of power generation is required for these operations. It is not clear how the risks of fugitive hydrocarbon gas emissions vary across the different techniques.
	Water resource depletion	Slight Rare Low 2	Minor Rare Low 4	Slight Rare Low 2	Low (likelihood and consequence not specified)	Minor Rare Low 4	Minor Rare Low 4	The risk of water resource depletion is similar for water flooding as for unconventional HVHF, due to the large volumes of water used. The risk is lower for enhanced recovery as lower quantities of water are used alongside chemicals or gas (known as water-gas-water or WGW injection). Steam injection may also use less water than water flooding because the density of steam is considerably lower than water.
	Traffic	Minor Rare Low 4	Slight Occasional Low 4	Slight Occasional Low 4	Moderate (likelihood and consequence not specified	Minor Occasional Moderate 6	Minor Occasional Moderate 6	The risks of traffic for water flooding and substance injection are lower than for unconventional HVHF, due to the need to manage flowback. In substance injection whilst traffic is required to deliver chemicals, much of

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Conventional – water flooding (consequence, likelihood and overall risk)	Conventional – substance injection (consequence, likelihood and overall risk)	HF - shale gas (consequence, likelihood and overall risk)	HF - tight gas (consequence, likelihood and overall risk)	HF - tight oil (consequence, likelihood and overall risk)	Reason for variance
					with measures in place)			what is injected into the well is intended to remain underground to increase the recovery rate of the hydrocarbons. This is similar in water flooding, and it typically takes a considerable amount of time before additional produced water is recovered from the well following a water flooding. In contrast, significant volumes (5-40% of injection volume (Boschee, 2014)) of flow back occur following unconventional HF, which requires additional traffic to export to a treatment or injection facility.
	Land take	Minor Occasional moderate 6	Minor Likely moderate 8	Minor Likely Moderate 8	Minor Likely moderate 8	Minor Likely moderate 8	Minor Likely moderate 8	Landtake is generally the same for enhanced recovery and unconventional HF. This is because similar equipment is used and space is required for chemical stores, demineralisation plants, injection wells, truck parking etc. for all the techniques. In some cases flowback from HF may be stored on site, but this is not thought to make a significant overall difference to the land take. It should be noted however that land take is highly location-dependent and outside the EU the extent of landtake for e.g. shale

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Conventional – water flooding (consequence, likelihood and overall risk)	Conventional – substance injection (consequence, likelihood and overall risk)	HF - shale gas (consequence, likelihood and overall risk)	HF - tight gas (consequence, likelihood and overall risk)	HF - tight oil (consequence, likelihood and overall risk)	Reason for variance
								gas plays can be significant.
	Noise	Slight Occasional Low 4 (mitigated) Minor Occasional Moderate 6 (unmitigated)	Slight Occasional Low 4 (mitigated) Minor Occasional Moderate 6 (unmitigated)	Slight Occasional Low 4 (mitigated) Minor Occasional Moderate 6 (unmitigated)	Minor Occasional Moderate 6 (unmitigated, from AEA (2012))	Minor Occasional Moderate 6 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Minor Occasional Moderate 6 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	This aspect is not included with measures applied for unconventional HF in the 2015 report, therefore unmitigated risk from AEA (2012) is compared instead. It is not expected to change significantly once measures are applied, as all injection operations produce noise due to the equipment used.
	Visual impact	Slight Rare Low 2 (mitigated) Slight Rare Low 2	Slight Rare Low 2 (mitigated) Slight Rare Low 2	Slight Rare Low 2 (mitigated) Slight Rare Low 2	Slight Likely Low 4 (unmitigated, from AEA (2012))	Slight Likely Low 4 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler	Slight Likely Low 4 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler	This aspect is not included for unconventional HF with measures applied in the 2015 report. AEA (2012) suggests the risk is slightly higher for unconventional operations than conventional. This is due to the higher density of well pads for fracturing operations in unconventional wells.

Stage	Aspect	Conventional HF (consequence, likelihood and overall risk)	Conventional – water flooding (consequence, likelihood and overall risk)	Conventional – substance injection (consequence, likelihood and overall risk)	HF - shale gas (consequence, likelihood and overall risk)	HF - tight gas (consequence, likelihood and overall risk)	HF - tight oil (consequence, likelihood and overall risk)	Reason for variance
		(unmitigated)	(unmitigated)	(unmitigated)		(2015a))	(2015a))	
	Seismic	Slight Rare Low 2 (mitigated) Slight Rare Low 2 (unmitigated)	Slight Rare Low 2 (mitigated) Slight Rare Low 2 (unmitigated)	Slight Rare Low 2 (mitigated) Slight Rare Low 2 (unmitigated)	Slight Rare Low 2 (unmitigated, from AEA (2012))	Slight Rare Low 2 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	Slight Rare Low 2 (unmitigated – deemed to be the same as for shale gas in Amec Foster Wheeler (2015a))	The risks of induced seismicity are similar for both enhanced recovery and HF. This is because injecting substances at high pressure into formations always carries a small risk of seismicity.

The values of risk attached to these aspects for enhanced recovery and fracturing are approximate only. They are estimates in relation to the parameters that define each well type and are not universally applicable, as each fracturing operation has varying levels of risk based on numerous factors which are not captured in this evaluation. Furthermore, it has not been feasible within the current study to compare the cumulative impacts of multiple conventional wells/pads within a concession, compared to those for unconventional gas installations.

9. Environmental impacts and risks of offshore unconventional fossil fuels

9.1 Introduction

9.1.1 Overview

This section presents an assessment of the environmental impacts and risks and associated risk management measures for offshore unconventional hydrocarbon exploration and production. The purpose of this part of the study is, firstly, to assess environmental impacts and risks of the offshore development of unconventional fossil fuels and, secondly, to examine to what extent additional or different risk management measures are needed to address risks of offshore unconventional hydrocarbon exploration and production activities (as compared to onshore unconventional hydrocarbon development and offshore conventional risk management measures).

9.1.2 Previous studies

Following on from work regarding a risk management framework for unconventional gas that focussed on shale gas (AMEC, 2014), the European Commission commenced work to examine and contrast the environmental impacts of other unconventional hydrocarbons (specifically tight gas, tight oil and coal bed methane (CBM), or 'other unconventional hydrocarbons' [other UFF]) to establish the differences in the level of environmental risks compared to shale gas and whether measures developed for shale gas would be sufficient, appropriate and proportionate to the risks presented by other unconventional hydrocarbons (Amec Foster Wheeler, 2015a). To establish the differences, a structured approach was developed based on:

1. A review of risks defined for shale gas to establish applicability of the risk to other unconventional hydrocarbons and an indication of difference and variance where relevant; and
2. An assessment of the risks of other UFF to validate and augment the first stage assessment to ensure all relevant risks were identified.

The study identified whether risks arising from other unconventional hydrocarbons were the same, different (potentially greater or less) or new compared to those identified in the work on shale gas. Risks deemed to be different from shale gas were then assessed and the appropriateness and adequacy of measures defined for shale gas were reviewed against the identified risks for other UFF.

9.1.3 Approach for this study

A similar process was carried out for this study regarding offshore unconventionals by reviewing the risks of (a) onshore unconventional and (b) offshore conventional hydrocarbon exploration and production and contrasting the potential risks with the specificities of offshore unconventional hydrocarbons. This led to an examination of the suitability of measures already identified for onshore unconventionals and offshore conventionals in the context of the risks presented by offshore unconventionals and if necessary identification of additional measures required.

Firstly, consideration is given to which unconventional hydrocarbons should be included in the assessment for offshore as not all unconventional hydrocarbons identified for onshore applications are also developed offshore.

9.2 Offshore unconventional hydrocarbons

Whilst exploration and production of shale gas, tight gas, tight oil and CBM has occurred onshore, not all hydrocarbons types may have potential offshore opportunities in the EU. Evidence has been found of offshore tight gas exploration and production in the Southern North Sea in the Chiswick and Babbage fields (the latter starting production in 2010, lying at a depth of 3,200m and having an estimated reserve of five bcm) (Marcus, 2010 and Offshore Technology, 2015), in the Dutch Sector of the North Sea (Schrama, 2012) and in the Kew Field (which has proven recoverable reserves estimated at 1.1 bcm) (Thomas, 2015). In addition the West Sole field has similar geology (Rotliegendes sediments[101]) extending across the southern North Sea. Whilst offshore tight-gas is not well defined, it is generally accepted that permeability of the target formation needs to be higher than that for onshore tight-gas, due to the economics of offshore developments (Haider and Shaoul, 2013).

Regarding offshore shale gas, it has been reported that UK offshore reserves of shale gas could exceed one thousand trillion cubic feet (tcf), or five times the latest estimate of onshore shale gas of 200 tcf (SPE International, 2013). In January 2014, the UK Department of Energy and Climate Change (DECC) granted Nebula Resources three licences of two years duration to explore shale gas reserves in the Irish Sea (Harris, 2013), however following review of available information on Nebula Resources website, no evidence has been located that exploration has commenced under the licences.

In the UK DECC's, Energy and Climate Change Committee Fifth Report on Shale Gas (DECC, 2011), it was recorded that costs of offshore shale would make projects economically unviable at current (i.e. 2011) market prices and that for offshore unconventional gas, it would require a pioneering approach as the expertise does not exist elsewhere. Offshore reserves were viewed as being substantially greater than onshore reserves and issues for offshore were reported to be identical to those for onshore. Furthermore, it was suggested that as deviated wells from onshore have been used for conventional resources, such an approach may also be possible for unconventional resources102.

In addition to the offshore shale gas exploration licences issued in the UK by DECC, seven offshore licences have been issued in Poland to Lotos Petrobaltic SA for offshore shale gas exploration (PGS, 2015). Most of the licences were issued in 2001 and all expire in 2016. Following reviewing licence information on Lotos Petrobaltic SAs website (October 2015), no evidence has been located that exploration has been commenced under the licences.

For tight oil, techniques such as fracturing are deemed to be uneconomic for offshore applications (Oil & Gas UK, 2011), particularly where water injection and gas injection have already been used to enhance recovery, which reduces the potential for such techniques as hydraulic fracturing. No evidence of the existence of offshore tight oil has been identified.

Regarding CBM, no evidence of the existence of offshore CBM has been identified.

Considering the above review of reserves and current and planned exploration and production of offshore unconventional hydrocarbons, the assessment has focussed on

[101] The Rotliegendes formation is a tight formation in the North German Basin that extends into the North Sea.
[102] Note however, that onshore deviated wells may extend approximately 1,350m horizontally (AMEC, 2014) which would limit the distance offshore that could be worked from onshore facilities.

the potential environmental impacts and risks of offshore tight gas. It should be noted that offshore shale gas may be developed in the future, but this has not been considered here.

9.3 Approach to identification of risks and impacts

The following approach was developed to identify risks and impacts specific to offshore tight gas:

1. Risks and impacts identified in section 6 associated with conventional offshore gas exploration and development were assumed to be fully relevant and the measures fully available to offshore unconventional tight gas[103] exploration and development;
2. Information within previous reports for the Commission (Amec Foster Wheeler 2014 and 2015a) that focussed on onshore unconventional gas exploration and development was reviewed to identify the specific risks associated with onshore unconventionals operations that are relevant to offshore tight across the lifecycle. Those aspects that were not applicable in the offshore operations were screened out (e.g. groundwater contamination, land take and road traffic impacts). Marine traffic impacts for drilling operation have been taken into account for the risk assessment in the relevant sections of this report. Shipping of the oil and gas to distribution points are considered outside the scope of this review. Additionally, in Amec Foster Wheeler (2015a) no evidence of enhanced recovery techniques used in unconventional wells was found. Therefore these sub-stages are omitted from the comparison of aspects in the 'production' lifecycle stage;
3. For those aspects that were not screened out, an assessment was made of whether or not the associated risks and impacts at the various life cycle stages are comparable with those of offshore conventionals; and
4. Those risks and impacts that were not comparable with offshore conventionals were taken forward for further evaluation, in particular to review the appropriateness and proportionality of measures already identified for onshore tight. Those aspects for which there was insufficient evidence to make this judgement were highlighted, but not taken forward for a review of measures.

9.4 Screening results

The results of stages 2 and 3 of the risks and impacts identification process are presented in Table 9.1. The outcome of stage 2 (identification of risks associated with onshore unconventionals operations relevant to offshore tight) can be summarised as follows:

- **Groundwater contamination and other risks**: assessed as not applicable at any stage due to operations being carried out offshore away from groundwater resources and screened out;
- **Surface water contamination**: assessed as not applicable at any stage due to operations being carried out offshore away from surface water resources. However, discharges to sea is relevant and hence a '*discharges to sea*' aspect was carried through to the following stage for further assessment;
- **Water resource depletion**: assessed as comparable to onshore activities at the technical hydraulic fracturing stage of the lifecycle due to a need to use freshwater

[103] No known shale gas drilling activity is being carried out offshore in Europe as of September 2016, according to IOGP.

for fracturing fluid and hence carried through to the following stage for further assessment;[104];

- **Releases to air**: not comparable at some stages due to onshore impacts being associated partly with emissions from, vehicles and mobile plant; however the aspect remains relevant as equivalent releases may arise from shipping and power generation equipment for offshore installations; similarly, fugitive emissions of methane may arise both offshore and onshore; the 'releases to air' aspect was carried through the following stage for further assessment;
- **Landtake**: assessed as not applicable at any stage due to operations being carried out offshore and hence was screened out;
- **Biodiversity impacts**: not comparable at all stages due to onshore vs. offshore location of developments; however impacts remain relevant in an offshore context. The 'biodiversity impacts' aspect was carried to through the following stage for further assessment as Marine biodiversity impacts;
- **Noise impacts**: noise impacts for onshore unconventionals focussed machinery noise and impacts on biodiversity (fauna) and local populations. Assessed as not comparable at all stages due to onshore vs. offshore location of developments. However noise impacts remain relevant in an offshore context for different reasons (e.g. impacts on cetaceans). The 'noise impacts' aspects was carried through the following stage for further assessment regarding Underwater noise;
- **Visual impact**: assessed as not applicable but related to near shore impacts. Visual impact carried through to the next stage;
- **Seismicity**: for onshore unconventionals, seismicity focussed on induced seismicity from fracturing/enhanced recovery and associated risks and impacts (e.g. damage to buildings and underground structures). Assessed as not comparable to onshore activities but remains a relevant aspect. The 'seismicity' aspect was carried through the following stage for further assessment; and
- **Traffic**: assessed as not applicable at any stage due to operations being carried out offshore using marine vessels and screened out. Marine traffic impacts for drilling operation have been taken into account for the risk assessment in the relevant sections of this report. Shipping of the oil and gas to distribution points are considered outside the scope of this review.

The outcome of stage 3 (whether or not the risks and impacts at the various stages are comparable with those of offshore conventionals) can be summarised as follows:

- **Seabed disturbance:** activities, risks and impacts across all stages were assessed as being comparable to conventional offshore activities and hence screened out. This is because minimal additional subsea infrastructure is required for hydraulic fracturing wells;
- **Discharges to sea**: for this aspect, risks and impacts across all unconventional lifecycle stages except 'technical hydraulic fracturing' and 'post closure and abandonment' were assessed as being comparable to conventional offshore activities. For the high volume technical hydraulic fracturing stage in unconventionals, management of considerably greater volumes of flowback (including handling, storage, recycling and treatment prior to discharge) is required compared to well stimulation through low volume fracturing in conventional wells. Flowback treatment processes (i.e. risk management measures) required prior to discharge of treated flowback to sea may differ from

[104] The use of seawater has been investigated (e.g. by Total, http://en.skifergas.dk/technical-guide/what-is-hydraulic-fracturing.aspx; Schlumberger 2009, http://www.slb.com/resources/technical_papers/technical_challenges/unconventional_gas/121204.aspx; and Norton Rose Fulbright, 2015, http://www.nortonrosefulbright.com/knowledge/publications/129578/an-introduction-to-shale-gas-and-hydraulic-fracturing. However, this appear to be an emerging technology hence freshwater is assumed to be used as per onshore fracturing.

those processes required for other non-hydraulic fracturing related wastewaters (e.g. sewage or other process wastewaters), depending on the additives and proppants used. Therefore this aspect was brought forward for consideration of measures. Regarding post closure, concerns have been raised by the US EPA (2016) around the long-term effects of re-fracturing and acids on old cement leading to well integrity failure. There is therefore not sufficient evidence to make a judgement as to whether or not the likelihood of a long-term leak increases for an unconventional well as compared to a conventional well, therefore this aspect was not taken forward for the consideration of measures, but was highlighted as 'unclear' in the assessment. This aspect would warrant further research and investigation as further evidence emerges;

- **Water resource depletion**: assessed as comparable to tight gas at the technical hydraulic fracturing stage of the lifecycle due a need to use large quantities of freshwater for fracturing fluid and not comparable to conventional offshore water resource requirements, even when low volume hydraulic fracturing is employed. Some offshore fracturing operations may use seawater, rather than shipping freshwater from shore (in which case this does not apply);
- **Releases to air**: Whilst extra equipment is generally required for pressurisation and injection related to high volume fracturing, this is not expected to significantly impact the overall emissions from the rig due to the large quantity of power generation required for conventional extraction, particularly if low volume HF or miscible gas injection is employed. There is some data (Carbon Brief, 2012) that suggests that the risks of fugitive methane leaks are greater in unconventional than conventional wells. However, this is disputed by industry. As a result there is not sufficient evidence to make a judgement as to whether or not the likelihood of a fugitive leak increases for an unconventional well as compared to a conventional well; therefore this aspect was not taken forward for the consideration of measures, but was highlighted as 'unclear' in the assessment;
- **Physical presence**: Whilst rig size is expected to increase slightly in order to accommodate extra storage of chemicals/proppants and equipment for unconventional hydraulic fracturing, the physical presence of the rig is not expected to change significantly enough to substantially increase environmental risk. This is because facilities for chemicals storage and pressurisation are also required on conventional installations, particularly those using low volume hydraulic fracturing. Therefore activities, risks and impacts across all stages were assessed as being comparable to conventional offshore activities and hence screened out;
- **Marine biodiversity impacts**: stages where the main biodiversity impacts arise (e.g. offshore platform installation, well drilling) are comparable between offshore conventional and unconventional. Provided that proper well integrity is ensured, additional biodiversity risks and impacts at the hydraulic fracturing stage were judged as not significant in comparison and hence screened out;
- **Underwater noise**: stages where the main noise impacts arise (e.g. offshore platform installation, well drilling) are comparable between offshore conventional and unconventional. Noise risks and impacts at the hydraulic fracturing stage were assessed as not significant in comparison to platform installation and well drilling and hence were screened out;
- **Visual impacts for nearshore operations**: activities, risks and impacts across all stages were assessed as being comparable to conventional offshore activities and hence screened out; and
- **Seismicity**: fracturing and enhanced recovery activities are at depth beneath the seabed and were assessed as having a slight potential for induced seismicity impacts on marine mammals. Such impacts may be similar to those described for the underwater noise impacts category for conventional offshore activities (e.g.

potential impacts on cetaceans). Underwater noise resulting from low volume hydraulic fracturing and enhanced recovery is considered as an aspect in conventional offshore extraction, and induced seismicity from fracturing operations is not expected to increase significantly with scale, because pressures do not increase greatly. Therefore activities, risks and impacts across all stages were assessed as being comparable to conventional offshore activities. However, it is recognised that low volume hydraulic fracturing and enhanced recovery is not systematically applied to all conventional offshore wells, therefore this aspect has been carried forward so that appropriate measures can be identified.

Following the stage 2 and 3 screening exercises, the following aspects were taken forward for further assessment of risks, all relate to stage 3, technical hydraulic fracturing, and to stage 5,

- **Discharges to sea;**
- **Water resource depletion –** only if freshwater for fracturing is shipped from shore**;**
- **Releases to air -** increased risk of fugitive methane emissions; and
- **Seismicity (induced) linked to fracturing –** only where low volume hydraulic fracturing/enhanced recovery is not applied as part of the conventional lifecycle.

The following risk assessment in Table 9.1 was formulated using expert judgement and, where available, secondary sources.

Table 9.1: Screened offshore unconventional[105] aspects

Stage	**Sub-stages**	**Aspect [1]**	**Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?**	**Are risks and impacts of offshore unconventionals comparable to offshore conventionals?**	**Comment**
1. Site identification and preparation	Desk studies, licensing, surveys	Groundwater contamination and other risks	Not applicable	Not relevant to offshore	
		Seabed disturbance	Not relevant to onshore	Not applicable	
		Surface water contamination risks / Discharges to sea	Not applicable	Not applicable	
		Water resource depletion	Not applicable	Not applicable	
		Releases to air / Releases to air	Not applicable	Yes	Offshore aspects related to releases to air from shipping and power generation / equipment on the rig are relevant. For this stage activities, risks, impacts are deemed to be comparable to the equivalent stage of an offshore conventional well, as the processes are identical.

[105] The review focused on experience to date mainly with tight gas extracted offshore. Whereas there are licenses allowing shale gas exploration offshore in the EU, to date there have been no wells targeting offshore shale gas being drilled in Europe. IOGP, September 2016

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
		Land take / Physical presence	Not applicable	Not applicable	
		Biodiversity impacts / Marine biodiversity impacts	Not applicable	Not applicable	
		Noise / Underwater noise	Not applicable	Yes	Offshore aspect Underwater noise is relevant. Underwater noise is expected to be identical for this stage of lifecycle for offshore conventional and unconventional, as the processes are the same. Activities, risks, impacts are therefore comparable.
		Visual impact / Visual impact for nearshore operations	Not applicable	Not applicable	
		Seismicity	Not applicable	Not applicable	
		Traffic (onshore)	Not applicable	Not relevant to offshore	

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
2. Well design, construction and completion	Well design, transport of drilling rig, well drilling, fracturing, well completion	Groundwater contamination and other risks	Not applicable	Not relevant to offshore	
		Seabed disturbance	Not relevant to onshore	Yes	Activities, risks, impacts are comparable. Unconventional offshore wells do not require additional seabed disturbance as the seabed infrastructure is essentially the same as a conventional well. For disturbances related to seismicity, see the aspect 'seismicity'.
		Surface water contamination risks / Discharges to sea	Not applicable	No	Discharges to sea is applicable. Treatment and discharge of significantly higher volumes of fracturing fluid is required, as compared to low volume hydraulic fracturing. Greater capacity of facilities for flowback management, recycling, storage, treatment prior to discharge required. Additional chemicals storage required.

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
		Water resource depletion	Yes	No	Water requirement for high volume fracturing is higher than LVHF. Assuming that this is shipped from shore then there are additional risks of water resource depletion. Seawater is sometimes used for offshore fracturing (Bukovac et al, 2009). In this instance there is therefore no additional risk.
		Releases to air / Releases to air	Not applicable	Unclear	Offshore aspects related to releases to air from ships are relevant. Whilst extra equipment is required for pressurisation and injection related to high volume fracturing, this is not expected to significantly impact the overall emissions from the rig due to the large quantity of power generation and shipping required for conventional extraction, particularly if low volume HF or miscible gas injection is employed. There is some evidence (Carbon Brief, 2012) to suggest that the risks of fugitive methane releases are higher in unconventional wells than conventional wells, but the literature is

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
					inconsistent therefore no firm conclusions can be drawn.
		Land take / Physical presence	Not applicable	Yes	Offshore physical presence is relevant. Whilst rig size is expected to increase slightly in order to accommodate extra storage of chemicals/proppants and equipment for high volume hydraulic fracturing, the physical presence of the rig is not expected to change significantly enough to increase environmental risk. This is because facilities for chemicals storage and pressurisation are also required on conventional rigs, particularly those using low volume hydraulic fracturing. Activities, risks, impacts are comparable.
		Biodiversity impacts / Marine biodiversity impacts	Not applicable	Yes	Offshore aspect Marine biodiversity impact is relevant. Stages where the main biodiversity impacts arise (e.g. offshore platform installation, well drilling) are comparable between offshore conventional and unconventional. Provided that

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
					proper well integrity is ensured, additional biodiversity risks and impacts at high volume hydraulic fracturing stage were judged as not significant in comparison, therefore activities, risks, impacts are comparable.
		Noise / Underwater noise	Not applicable	Yes	Offshore aspect Underwater noise is relevant. Stages where the main noise impacts arise (e.g. offshore platform installation, well drilling) are comparable between offshore conventional and unconventional. Noise risks and impacts at high volume hydraulic fracturing stage were assessed as not significant in comparison to platform installation and well drilling. Underwater noise as a result of induced seismicity from fracturing is considered in the aspect 'seismicity'. Therefore activities, risks, impacts for non-seismic sources of underwater noise are comparable.

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
		Visual impact / Visual impact for nearshore operations	Not applicable	Yes	Visual impact for nearshore operations is comparable.
		Seismicity	Not applicable	Yes	Potential for induced seismicity risks and impacts in marine environment associated with fracturing. Underwater noise resulting from induced seismicity associated with low volume hydraulic fracturing is considered as a sub stage in conventional offshore extraction, and induced seismicity from fracturing operations is not expected to increase significantly with scale, because pressures do not vary greatly. For conventional wells where enhanced recovery using low volume fracturing is not applied, the risks of this aspect will be lower than an unconventional well.
		Traffic (onshore)	Not applicable	Not relevant to offshore	

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
3. Production	Platform installation, platform operations	Groundwater contamination and other risks	Not applicable	Not relevant to offshore	
		Seabed disturbance	Not relevant to onshore	Yes	Activities, risks, impacts are comparable. For disturbances related to seismicity, see the aspect seismicity.
		Surface water contamination risks / Discharges to sea	Not applicable	No	Discharges to sea is applicable. Treatment and discharge of large volume of fracturing fluid required (if well is refractured during production at high volumes). Additional flowback management compared to low volume fracturing is required, including recycling, storage and treatment prior to discharge required. Additional chemicals storage required.
		Water resource depletion	Yes	No	Assuming additional freshwater is required for re-fracturing (if required) Water resource requirements additional compared to offshore conventional using low volume hydraulic fracturing due to greater quantities of water.

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
		Releases to air / Releases to air	Not applicable	Unclear	As with stage 2 Well design, construction and completion, emissions from equipment are not expected to change significantly. Regarding fugitive emissions of methane, although there is some evidence to suggest that risks may be higher for UFF than CFF, the literature is not consistent therefore no firm conclusions can be drawn.
		Land take / Physical presence	Not applicable	Yes	See stage 2 Well design, construction and completion
		Biodiversity impacts / Marine biodiversity impacts	Not applicable	Yes	See stage 2 Well design, construction and completion
		Noise / Underwater noise	Not applicable	Yes	See stage 2 Well design, construction and completion
		Visual impact / Visual impact for nearshore operations	Not applicable	Yes	Visual impact for nearshore operations is comparable.

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
		Seismicity	Not applicable	Yes	Due to re-fracturing. As with underwater noise created by induced seismicity for the original fracturing process, risk is not expected to change significantly compared to low volume fracturing (assuming LVHF is employed in conventional offshore wells).
		Traffic (onshore)	Not applicable	Not relevant to offshore	
4. Project cessation and well closure	Well closure, management of cuttings and piles	Groundwater contamination and other risks	Not applicable	Not relevant to offshore	
		Seabed disturbance	Not relevant to onshore	Yes	In (Amec Foster Wheeler, 2015a), conventional extractions were classified as occurring between 1800-5500m depths. Unconventional extractions were classified as between 1800-4200m for tight gas. The well depth will vary proportionally with the quantity of drill cuttings and hence the seabed disturbance caused by the pile. However, as the ranges of depths for both CFFs and UFFs appear to

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
					be broadly comparable, The quantities of drill cuttings produced by conventional and unconventional wells should be broadly comparable. Therefore this is no significant change in risk.
		Surface water contamination risks / Discharges to sea	Not applicable	Yes	See the comment above for 'seabed disturbance'. The quantity of drill cuttings (and hence well depth) is also related to the risk of surface water contamination. However, well depth does not appear to change significantly between CFFs and UFFs.
		Water resource depletion	Not applicable	Not applicable	
		Releases to air / Releases to air	Not applicable	Yes	See the comment above for 'seabed disturbance'. The quantity of drill cuttings is also related to the risks of releases to air. This is because more equipment is required to manage a larger cutting pile.
		Land take / Physical presence	Not applicable	Yes	See the comment above for 'seabed disturbance'. The quantity of drill cuttings (and therefore well depth) is also related l to the physical

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
					presence of the cuttings pile. However, well depth does not appear to change significantly between CFFs and UFFs.
		Biodiversity impacts / Marine biodiversity impacts	Not applicable	Not applicable	
		Noise / Underwater noise	Not applicable	Yes	See the comment above for 'seabed disturbance'. The quantity of drill cuttings (and therefore well depth) is also related to the amount of noise generated when the pile is managed. However, well depth does not appear to change significantly between CFFs and UFFs.
		Visual impact / Visual impact for nearshore operations	Not applicable	Not applicable	
		Seismicity	Not applicable	Not applicable	
		Traffic (onshore)	Not applicable	Not relevant to offshore	

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
5. Post closure and abandonment	Topside, jacket and pipeline & bundle decommissioning, shipping	Groundwater contamination and other risks	Not applicable	Not relevant to offshore	
		Seabed disturbance	Not relevant to onshore	Yes	Activities, risks, impacts are comparable. Although there will be slightly more equipment for associated with high volume hydraulic fracturing for unconventional wells, this is not expected to have a significant impact on the risk of this aspect, owing to the large amount of heavy materials required for processes which are used in both conventional and unconventional wells.
		Surface water contamination risks / Discharges to sea	Yes	Unclear	A study (Ingraffea et al, 2014) analysed the risks of well integrity failure in over 41,000 onshore wells in Pennsylvania during 2000-2012. It found that unconventional shale gas wells were 6 times more likely to experience 'loss of structural integrity' than conventional wells (6.2% vs 1%). This is the change of a single cement casing failing.

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
					As modern wells often have multiple layers of redundant casing for safety, this does not represent the likelihood of an actual leak, which is expected to be far lower. This data was collected for active wells. Once decommissioned, pressures are no longer applied and hence there is less stress on containment equipment. According to industry (ConocoPhillips, 2013), once a modern well is properly decommissioned, the risk of long-term well integrity failure is extremely low. However, the US EPA (2016) have highlighted the need for more information on the long-term integrity of aging wells that have been fractured/re-fractured, as there are concerns around the degradation of old cement due to re-fracturing processes and the use of acids. There is therefore not sufficient evidence to make a judgement as to whether or not the likelihood of a long-

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
					term leak increases for an unconventional well. The difference between the quantity of residual fracturing fluids left in UFF and CCF wells (that have used HF for stimulation) is not thought to be significant enough to change the consequence category of a discharge to sea resulting from a leak.
		Water resource depletion	Not applicable	Not applicable	
		Releases to air / Releases to air	Not applicable	Yes	Activities, risks, impacts comparable. There is not enough additional equipment required for unconventional hydraulic fracturing to significantly increase this risk compared to a conventional well.
		Land take / Physical presence	Not applicable	Yes	Offshore physical presence is relevant. Activities, risks, impacts are comparable. There is not enough additional equipment required for unconventional hydraulic fracturing to significantly increase this risk compared to a conventional well.

Stage	Sub-stages	Aspect [1]	Are risks and impacts of offshore unconventionals comparable to onshore unconventionals?	Are risks and impacts of offshore unconventionals comparable to offshore conventionals?	Comment
		Biodiversity impacts / Marine biodiversity impacts	Not applicable	Not applicable	
		Noise / Underwater noise	Not applicable	Yes	Activities, risks, impacts comparable. There is not enough additional equipment required for unconventional hydraulic fracturing to significantly increase this risk compared to a conventional well.
		Visual impact / Visual impact for nearshore operations	Not applicable	Not applicable	
		Seismicity	Not applicable	Not applicable	
		Traffic (onshore)	Not applicable	Not relevant to offshore	

Notes:

1. Aspects for onshore unconventionals and offshore conventionals are listed together where they are related, e.g. 'Surface water contamination risks / Discharges to sea' and 'Noise / Underwater noise'. Offshore-specific aspects are in blue text.

9.5 Risk assessment

The risk assessment of the aspects brought forward from the screening exercise are presented in the table below. The risk matrix presented in section 4.2 was used to determine the overall risk ranking. Measures that are assumed to be in place are as follows[106]:

- Discharges to sea:
    - Good practice to prevent leaks and spills. Employees implement good operational practices and are appropriately trained to prevent leaks and spills;
    - Spill kits available for use: Spill kits to contain and clear up spills of liquids;
    - Use of tank level alarms. Alarms in place to avoid overfilling of tanks containing chemicals and/or waste water;
    - Treatment of produced water to standards for oil content as described previously for conventional offshore activities (under the HELCOM, OSPAR and Barcelona Conventions)[107];
    - Addressing the hazards/risks of chemicals used in fracturing fluids (and hence present in flowback) through requirements on general aspects of chemical use (for all offshore operations), such as those under the Harmonised Mandatory Control System for chemicals under OSPAR (and other requirements under HELCOM and the Barcelona Convention, as well as through REACH as described earlier). It is noted that the requirements on chemical selection vary amongst regions in the EU (MAP, 2014), and that even within the OSPAR region approaches differ amongst member countries (ChemicalWatch, 2014)[108];
    - Emergency plans, including spill clean-up procedures and accident logs;
    - Strategic placement of tanks within the installation to provide added protection of collisions;
    - Separation between process areas and storage areas with minimum distance for separation; and
    - Drainage systems for capture of spillages including oil separation at bilge tank.
- Water resource depletion (only if freshwater is shipped from shore for fracturing):
    - Demand profile for water. Study to provide an informed prediction of the onshore water demand/extraction for fracturing (both ground and surface water) during the wells' operational life;
    - Water management plan. Development of a water and wastewater management plan to cover water supply and efficient use on site (e.g. recycling of flowback); and

[106] The measures for Discharges to sea and Water resource depletion mirror those that were assumed to be applied for onshore unconventional gas in Amec Foster Wheeler 2014 and 2015a to mitigate risks arising from activities linked to fracturing and those in section 6 regarding offshore conventionals.
[107] It is treated and disposed of at sea, but potentially could be returned to shore in some cases, which would be expected to be rare and the risk minor based on O&G total operations.
[108] There are also gaps in implementation by member countries of requirements under international conventions e.g. as highlighted in the MAP (2014) report on the Barcelona Convention.

    - Establishment of water source availability and tests for suitability. Available water resources are established which will influence operational factors (e.g. number of shipments of water) and environmental impact of operation.
- Seismicity (induced) linked to fracturing/enhanced recovery – both well stimulation and enhanced recovery in conventional wells and unconventional wells:
    - Measures as per offshore conventionals relating to underwater noise[109] (see section 6.2, e.g. delay work if cetaceans are located in the area by MMOs or PAM and use of 'soft-start' operations); and
    - In the context of induced seismicity and well integrity, application of the draft revision of ISO/TS 16530-2:2014 'Well integrity – Part 2: Well integrity for the operational phase' which requires the design phase to consider risks of activities that may be performed during the well life cycle that affect well integrity. This includes designing for identified hazards to reduce the risks to an acceptable level such that the well is fit for its intended purpose throughout its life cycle. The risk of fracturing into adjacent, abandoned or legacy wells, either while injecting or during stimulation' is noted as a relevant activity. In addition, consideration is also required of external and environmental risks, and life cycle control measures should be considered in the well design, as appropriate regarding aspects such as 'external loads on wells as a result of seismic activity, or movement of faults'.

For all aspects, taking account of the above risk management measures, the risk levels were determined as 'low' for high volume fracturing. As per the risk assessment for conventional offshore, if measures were not in place there is a potential for increased risk levels for all of these aspects.

[109] Mitigation measures relating to underwater noise (i.e. due to vibration from drilling) are also relevant to Seismicity (from fracturing) due to commonality of the nature of risk (i.e. stemming from noise/vibration).

Table 9.1: Risk assessment of screened offshore unconventional aspects

Stages	Sub-stages	Processes / technologies	Environmental Aspects	Expected risk management measures	Receptor	Impacts	Risk Characterisation (with expected risk management measures in place)	Risk Characterisation (without expected risk management measures in place)
2. Well design, construction and completion and 3. Production	Hydraulic fracturing	Flowback storage, handling, treatment and disposal Extraction of freshwater onshore for use in fracture fluid Hydraulic fracturing	• **Discharges to sea**: of treated flowback (but potentially could be returned to shore. These cases are considered rare). • **Water resource depletion**: of freshwater onshore • **Seismicity (induced)**: from hydraulic fracturing activity (both low and high volume) and enhanced recovery	• Refer to section above for expected risk management measures.	• Discharges to sea: marine environment • Seismicity (induced): cetaceans and marine environment • Water resource depletion: onshore water resources and water quality	• Discharges to sea: marine pollution • Water resource depletion: reduction in onshore water resources and water quality • Seismicity (induced): disturbance of cetaceans and pollution of marine environment	**Discharges to sea**: Likelihood - likely, Consequence - slight, Risk: 4 low **Water resource depletion**: Likelihood - rare, Consequence - minor, Risk: 4 low. Because unconventional operations are highly water intensive, measures cannot reduce the likelihood below rare and have no effect on the consequence, therefore there is no change in risk. **Seismicity**: Likelihood - rare, Consequence - slight, Risk: 2 low	**Discharges to sea**: Likelihood - likely, Consequence - minor, Risk: 8 moderate **Water resource depletion**: Likelihood - rare, Consequence - minor, Risk: 4 low **Seismicity**: Likelihood - occasional, Consequence - slight, Risk: 3 low

9.6 Evaluation of measures

9.6.1 Overview

For risks and impacts that were concluded to be comparable with offshore conventional gas, it was assumed that the measures for offshore conventional gas (see section 6) are also appropriate and proportionate for the offshore tight gas (and so these are not considered again here).

Where risks and impacts were identified as not comparable, the measures identified for onshore tight and shale gas were reviewed to consider whether they are appropriate and proportionate to the risks and impacts for offshore tight gas.

For these risks and impacts, the measures identified for onshore tight gas and shale gas were considered in the context of offshore tight gas for their appropriateness, i.e., whether or not the measure is suitable to address the risk offshore. Proportionality was then judged as being ‘over-specified’, ‘proportionate’ or ‘under-specified’.

Where a judgement could not be made for a certain process / aspect as to whether risks and impacts were comparable or not comparable between conventional and unconventional activities, this was highlighted in the assessment but measures were not considered for such processes as the evidence was inconclusive.

9.6.2 Discharges to sea measures

All measures considered in section 9.5 (above) were judged both appropriate and proportionate for offshore tight gas.

9.6.3 Water resource depletion measures

All measures considered in section 9.5(above) were judged both appropriate and proportionate for offshore tight gas. In terms of additional measures, further measures may be beneficial to address logistical aspects of providing freshwater to remote offshore locations whilst also addressing water resource depletion. The following additional measures are relevant:

- Reuse of flowback and produced water for fracturing (following treatment, e.g. chemical oxidation to remove organic compounds); and
- Use of lower quality water for fracturing. For example, rainwater harvesting, sea water, treated process wastewater from the platform.

9.6.4 Seismicity measures

All measures (see above) were judged both appropriate and proportionate for offshore tight gas.

10. Conclusions

10.1 Risks and impacts for conventional oil and gas

Section 2(Definition of activities for conventional onshore and offshore oil and gas) and Sections 4-6 (Risks and impacts) of this report lay out the processes and activities undertaken for the exploration and production of hydrocarbons from conventional oil and gas, including the identification of risks and impacts. Section 7 provides commentary around the measures that can be used to limit such risks. These are intended to provide a broad overview of techniques and processes; it should be recognised that there is much variability across the EU oil and gas industry, so the analysis should be viewed as illustrative, rather than comprehensive. It is for instance acknowledged that deeper or rougher seas, more windy conditions or colder temperatures may increase the likelihood of impacts and potentially the consequences. In addition, it is to be noted that cumulative impacts and risks (of multiple installations in a location) were not taken into account in this study.

As onshore and offshore oil and gas work within different physical environments the nature of the risks involved varies, but can broadly be assumed to differentiate in the following ways:

- The marine environment presents bigger challenges around the flow and containment of substances, particularly the storage and use of liquid substances needed in the drilling of wells and production of oil and gas from offshore installations. The movement of goods from onshore to offshore installations is also a key activity which may present higher levels of risk, with the risk matrix tables presented in Appendix B detailing the issues around accidental events, particularly collisions at sea, and additionally well blow-outs during drilling and production;
- Equally the issue of 'noise' within the marine environment and exposure of marine life, particularly cetaceans, to noise during the installation and drilling of wells poses a different kind of challenge to manage compared to the equivalent environmental aspect for onshore operations. The need to manage noise proactively within the marine environment includes a range of measures used to identify the presence of vulnerable species when activity is undertaken and sound limiting options for equipment such as soft-start;
- For the onshore operations the issues of 'built environment' pose greater challenges than seen for offshore. This includes for example the environmental aspects around air pollution from energy generating equipment which are closer to more sensitive receptors than in offshore conditions. Equally the use of road transport to move goods to and from site, due to the proximity to people, poses issues for the immediate environment around the well site and between the well site and waste facilities or water abstraction points; and
- Other environmental aspects onshore that differ in nature to the offshore activities relate to 'land-take' for placing of well sites in relation to the built environment, the use of water resources and water depletion given that even for conventional oil and gas use of water and gas for drilling is important. There is also the environmental aspect around groundwater and surface water contamination effects, noting that for onshore operations groundwater serves as an important resource for humans and wildlife alike; these are not relevant for offshore, whereas marine waters are.

The risk/impact assessment within Sections 4-6 has been carried out using the same methodology used in previous Commission studies for unconventional fossil fuels (shale gas, tight oil, tight gas and coal bed methane). It provides a breakdown of the risks and impacts of operations by life-cycle stage, process and sub-process to identify potential environmental consequences. The results of this assessment, which are provided with more detail within Appendices A & B., include an assessment of the identified risks based on the matrix shown in Section 4 and risk rating for mitigated and unmitigated risks (taking into account measures likely to be applied, whilst also recognising potential for geographical variability in the approaches, regulation, guidance and site-specific factors, at a high level). The Tables provided within Appendices A and Balso provide detail of the measures commonly used to manage risks and an indicative estimation of their potential uptake rates across the oil and gas industry.

This approach (which is discussed within section 4) has allowed an assessment of the risks across exploration and production of conventional oil and gas, and further review of those 'high' risks after measures have been put in place. In some cases the higher risk issues identified are related to accidental events as opposed to standard operations.

To help gauge the issue of accidental events for offshore in particular, an approach using a three tiered system commonly adopted by the offshore oil and gas industry has been utilised[110]. Section 6.4.7.1 provides details of how this approach works with the severity of the incident rising from tier 1 to tier 3. Although the same approach can be adopted for onshore operations, very limited information was found on its application for onshore.

There is a lack of consistent and peer reviewed information and data for onshore environmental risk events (for example, as highlighted by OGP, while there are data available for blowout and well release frequencies, for onshore operations, comparable data were not found (OGP, 2010). Therefore, a different approach was used to assess the risks. Accidental events that are considered major are those with catastrophic impacts or which require major long term monitoring and clean-up. Events that can be controlled quickly and do not require third party assistance are considered minor events.

In the case of offshore, the advent of the Offshore Safety Directive (2013/30/EU) is expected to have an ongoing effect on the management of risks of major accidents in the offshore industry. This is expected to further reduce the likelihood and consequence of major accidents over the coming years.

The risk rankings for each aspect in the report were assessed using expert judgement and relevant literature. They were also reviewed against previous reports for the Commission for coherence. It is recognised that in reality risk varies based on many site-specific factors. Therefore, the rankings have been provided for illustrative purposes only, and should not be considered as universally applicable to all hydrocarbon exploration and extraction activities.

10.2 Additional measures for aspects of high remaining risk

The risk assessment carried out and documented within sections 4-6 intended to assess the conventional oil and gas practices used within the exploration and production of hydrocarbons, taking into account the practices typically applied (to the extent possible given the available information). The assessment provides risks and impacts with risk ratings which might in some cases still be significant after measures had been adopted. The completion of this work then allowed the project team to identify in particular those risks which remained potentially high after measures had been adopted.

Those risks with higher scoring risk ratings were taken forward for further assessment to see what additional measures might be available to control the issues identified. The research in this case was intended to look at what practices were being developed

[110] http://www.ipieca.org/publication/guide-tiered-preparedness-and-response

or already available but not yet widely used within the oil and gas industry to help address these remaining higher level risks.

The results of this component (detailed in section 7.3) included:

- The remaining high risk aspects for offshore related primarily to accidental events, particularly tier III (high severity) incidents resulting from loss of containment at the well-head such as a blow-out. The remaining high risk aspects for onshore operations related more to the issues around land take and the need for ground clearance in order to prepare the site for establishment of a drilling operation;
- The additional measures identified were all either ready for use / being used by the oil and gas industry in a more limited fashion already, or in the latter stages (proven testing) of development meaning that they could be adopted in the near future, i.e. the industry is already taking steps to manage/reduce these risks;
- The kinds of additional measures identified for onshore operations related to the way in which drilling is carried out. The use of alternative drilling techniques such as 'coiled tubing', 'slimhole' and 'closed loop' would mean that the size of the site required to carry out drilling operations could be smaller and the quantity of waste generated less. This in turn would reduce the impact upon the environment from land clearance and preparation needed for drilling infrastructure;
- The kinds of additional measures identified for offshore operations related to either improved control and data gathering from live operations which could minimise the extent of an accidental event, either through earlier warning or through allowing prevention steps to be taken to avoid an event occurring. This included technologies such as 'measure while drilling (MWD)' to gather real-time data from the bottom of wells during drilling, or the use of robotics to help minimise the potential for human error while working at depth; and
- Additionally the offshore measures also highlighted bigger evolutions which could alter how existing processes currently work. In particular the use of floating liquefied natural gas (FLNG) installations can be used to process gas at sea prior to transmission back to shore. The processing of material at sea would reduce the need for gas liquefaction onshore and hence reduce potential onshore risks throughout the natural gas life cycle (e.g. related to land take and impacts of incidents onshore), although it would not reduce the environmental risks offshore.

10.3 Emerging technologies

The overview of oil and gas industry operations for conventional onshore and offshore detailed in section 2 provides a background to the current processes and activities being undertaken for exploration and production of hydrocarbons. However it has also been recognised that the oil and gas industry is dynamic and that new technologies are constantly being developed and brought to market in order to further improve the work undertaken by oil and gas companies.

Section 3 provides an overview of the key areas for emerging technologies that have potential for wider uptake in the near future. A number of these technologies such as FLNG, robotics and coiled tubing (drilling) overlap with the additional measures that could be used to reduce the 'high' rating risks for conventional oil and gas, which in part reflects the pro-active nature of the oil and gas industry to address the issues that are identified.

Emerging technologies include:

- Floating liquefied natural gas installations, which are processing facilities used at-sea used to manage the oil and gas generated. This kind of processing is usually carried out on shore with the raw material transported by pipeline;

- Robotics is an area of technology which has multiple applications, particularly operations carried out at depth. It allows automated or semi-automated operation of equipment reducing the risk both to personnel but also risk to the environment from human error during drilling operations;
- Coiled tubing drilling techniques which allow the drilling of wells using a faster setup and smaller installation size to achieve the same results. The commercial benefit being saving in time and effort as well as land-take. The environmental benefit is the reduced impact upon the land for clearance and installation of well equipment;
- The increasing application of nanotechnologies to engineer materials for use within the onshore and offshore environment which meet the engineering needs in a more bespoke way and reduce issues created from existing structural constraints. In some cases it is thought that this will reduce environmental risks through enhanced performance of the materials being used. However, due to their infancy, the full risks associated with the use of nanotechnologies remain unknown;
- The use of emerging enhanced recovery techniques to maximise the yields from oil and gas fields and prolong service life of wells. This recognises that use of water, gas, steam and polymers for pumping of oil and gas are techniques already in use within conventional oil and gas. Emerging ER further develops upon this approach to deliver higher yields of oil and gas. The environmental benefit from this technology would be the reduced need for exploration of new wells because existing ones can remain in production. However, environmentally there is also the potential for these technologies to present additional risks, including impacts to air, land, sea and surface runoff pollution;
- Seismic technologies can be used to more accurately assess the geology of formations and identify oil and gas deposits with greater success. These technologies mean the need for fewer exploration wells in order to identify viable production sites; and
- Low emissions technologies for energy generation equipment on site. These technologies are designed to run on specific fuel mixtures but produce lower emissions of air pollutants.

The full overview of the emerging technologies as well as a broad indication of the likelihood for widespread adoption by the oil and gas industry is provided within section 3.

10.4 Comparison of environmental impacts and risks of hydraulic fracturing and enhanced recovery techniques in conventional and unconventional onshore wells

The risk assessment for onshore conventional extraction and production included sections on low volume hydraulic fracturing and enhanced recovery techniques. These was compared to the risk assessment conducted in a previous report by Amec Foster Wheeler (2015a) and related work by AEA (2012) on onshore unconventional extraction and production, to determine how risks varied between low and high volume fracturing operations, and enhanced recovery techniques compared to unconventional HF, with management measures applied.

The values of risk attached to these aspects for different scales of fracturing are estimates that have been made using expert judgement. The magnitude of change in risk in relation to the parameters that defines each well type are not universally applicable, as each fracturing operation has varying levels of risk based on numerous factors which are not captured in this evaluation. Therefore, the outcome of the evaluation makes no attempt to quantify the variance in risk between low and high volume fracturing operations, and provides only an indication of which aspects are likely to scale with size.

Based on data from these previous studies, it was determined that volume of fluid injected was the key operator-controlled variable that changed significantly between the two. It is recognised that other factors such as depth and pressure of injection will also affect risk, but it is less clear how these vary between fracturing operations. Therefore as an approximation, risks and impacts related to the following aspects were shown to vary between high and low fracturing operations, and hence scale with the volume of fracturing fluid injected:

- Landtake: this is due to the additional space required to store larger quantities of chemicals/proppant, flowback, produced water and injection and pressurisation equipment;
- Traffic: this is due to the increased quantities of materials and equipment that must be brought to the site, combined with the additional flowback that may need to be transported for treatment;
- Surface water contamination: this is due to the increased volumes of chemicals/proppant stored on the site, resulting in a greater potential for contamination of nearby surface waters, were a spill or containment failure to occur;
- Water resource depletion: this is due to the higher volumes of water required for larger fracturing operations; and
- Visual impact: this is due to the increased density of well pads in unconventional fields.

The risks and impacts associated with the enhanced recovery techniques considered in the onshore assessment (water flooding and substance injection – polymer / steam / miscible gas) were also compared to the risks and impacts of HVHF in unconventional wells. A number of differences and similarities were identified, such as:

- Substance injection may cause risks of a potentially similar magnitude to hydraulic fracturing, due to the large quantities of chemicals stored and used above ground;
- Visual impacts of installations using substance injection and water flooding may be less than for wells involving HVHF, where there are often significant land-use requirements for multiple well pads (e.g. in the case of shale gas plays). They may therefore be more readily comparable to conventional wells; and
- Otherwise the risks associated with enhanced recovery techniques are broadly considered to be of a comparable scale to those associated with hydraulic fracturing, although the nature of those risks may clearly vary (e.g. types of substances used, above-ground equipment, etc.). However, it should be borne in mind that a precise comparison is not possible, due to the differences in activities involved.

10.5 Risks and impacts for offshore unconventional oil and gas

Upon completion of the earlier stages to assess the conventional oil and gas processes and activities for risks and impacts, an additional task was carried out to look at the unconventional oil and gas sector offshore. This work builds upon previous studies conducted on behalf of the Commission to assess the environmental risks and impacts of unconventional oil and gas for onshore operations. The previous studies covered unconventional oil and gas in terms of the exploration and production of hydrocarbons from shale gas (onshore), tight gas, tight oil and coal bed methane.

The current study has utilised the same method used previously to carry out a comparison exercise in two parts:

- Firstly to compare the activities for unconventional oil and gas offshore to those for onshore unconventional to identify what additional processes and activities might be needed as part of offshore unconventional oil and gas; and
- Secondly the comparison exercise then assessed for the offshore unconventional oil and gas, what measures used for conventional offshore might also be appropriate for unconventional offshore. The result of this comparison exercise intended to assess whether the additional aspects of unconventional offshore were suitably covered already by existing measures in the offshore industry, or whether additional measures may be needed to manage the risks identified.

The results of this phase of work concluded:

- The initial review of offshore activities highlighted that the exploration and production for tight gas was ongoing within Europe. Furthermore licenses have been taken out for the exploration and potential production of shale gas offshore. However the changing situation with oil and gas prices across Europe has meant that the active exploration for shale gas offshore has not occurred yet (no commercial production has been identified[111]). The exploration of tight oil offshore was deemed likely to be uneconomical and no record was found of licenses in place or activity pertaining to recovery of hydrocarbons from tight oils at sea. Equally coal bed methane at sea was recognised as being unlikely;
- The review therefore focused on tight gas. This identified a number of risks and impacts additional to conventional oil and gas, which were then assessed for relevance to the offshore environment. Following this review the following environmental aspects were identified as being relevant and additional to those for conventional offshore processes:
    - Discharges to sea (e.g. due to need for treatment of increased flowback quantities);
    - Water resource depletion (only if fresh water for use in fracturing is shipped from shore); and
    - Seismicity from fracturing (if low volume hydraulic fracturing/enhanced recovery are not employed in conventional wells).

  In addition, a judgement could not be made (due to conflicting evidence) as to whether risks differed for unconventional wells compared to conventional wells, for the following aspects:

    - Discharges to sea (due to long-term loss of well integrity following closure and abandonment); and
    - Releases to air (due to fugitive methane emissions during production).
- The risks and impacts associated with the environmental aspects that were identified as being relevant and additional to those for conventional onshore processes were then compared against the current management measures used by the conventional offshore oil and gas industry to assess whether they would be suitable to also manage these additional risks and impacts. Based on the conclusion of this review, which was conducted using expert judgement, and where possible substantiated with publically available industry data, the measures that are already available and likely to be applied offshore are considered to be capable of reducing the identified risks resulting from offshore tight gas extraction to a comparable level to that for other offshore activities. This conclusion excludes those aspects for which there is conflicting evidence as to whether risks are increased for unconventional activities as compared to conventional, specifically fugitive methane leaks and long-term well integrity failure.

[111] IOGP, September 2016

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Schrama	2012	Tight-gas horizontal well fracturing in the North Sea, Offshore Engineer, October 2012
Science & Technology	2013	Sustainability in the Pipeline http://editions.sciencetechnologyaction.com/lessons2-12689.php
Shell	2011	Shell environmental statement for UK operations'

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Siemens	Undated	Dry Low Emissions Experience across the range of Siemens Small Industrial Gas Turbines http://www.energy.siemens.com/nl/pool/hq/energy-topics/pdfs/en/techninal%20paper/Dry%20Low%20Emissions%20Experience.pdf
SPE International	2011	EOR –The Time is Now, conference proceedings http://www.spe.org/dl/docs/2011/Bondor.pdf
SPE International	2013	North Sea and European Area Stimulation, 5 – 7 November 2013 http://www.spe.org/events/13abar/pages/schedule/agenda.php
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Statistica	2014	Oil production in the European Union from 1998 to 2014 (in 1,000 barrels per day http://www.statista.com/statistics/265206/oil-production-in-the-european-union-in-barrels-per-day/
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Sundsbø Alne	2007	Reduction of NOx Emissions from the Gas Turbines for Skarv Idun', report by Norwegian University of Science and Technology Department of Energy and Process Engineering.
Thomas	2015	Offshore Southern North Sea Tight Gas Right on Kew, Mark Thomas, Hart Energy Wednesday, March 11, 2015 http://www.epmag.com/offshore-southern-north-sea-tight-gas-right-kew-786591
Tribal Energy	2015	Oil and gas exploration impacts http://teeic.indianaffairs.gov/er/oilgas/impact/explore/index.htm
Turbomachines	2015	http://turbomachinery.man.eu/
UK DECC	2014	Fracking UK shale: water', position paper published by the UK Department of Energy and Climate Change (DECC)
UK DECC	2015(a)	UK Department for Energy and Climate Change, oil and gas licensing website: https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/oil-and-gas-licensing

UK DECC	2015(b)	The Crown Estate Agreements including Leases, Licences, Agreements for Lease and Search Areas: https://www.gov.uk/oil-and-gas-offshore-maps-and-gis-shapefiles Guidance document published by the UK Department of Energy and Climate Change (DECC)
UK Environment Agency	2010	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/384624/LIT_10065.pdf
UKOOG	2015	Guidelines for the Establishment of Environmental Baselines for UK Onshore Oil and Gas, United Kingdom Onshore Oil and Gas.
Umweltbundesamt	2013	Environmental Impacts of Fracking Related to Exploration and Exploitation of Unconventional Natural gas Deposits. Risk Assessment, Recommendations for Action and Evaluation of Relevant Existing Legal Provisions and Administrative Structures
UNEP/O&G	1997	Environmental management in oil and gas exploration and production
US Department of Energy	2016	http://energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery
US EPA	1991	The Effects of well casing material on ground water-quality', US EPA guidance document
US EPA	2016	https://yosemite.epa.gov/sab/sabproduct.nsf/fedrgstr_activites/BB6910FEC10C01A18525800C00647104/$File/EPA-SAB-16-005+Unsigned.pdf
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Varhaug	2014	Big reels at the well site', Oilfield review
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Williamson, D	2013	Drilling Fluid Basics', Oil field Review, Spring edition published by Schlumberger
Woodside	2014	Browse FLNG Development – Draft Environmental Impact Statement
World Petroleum	2010	http://www.world-petroleum.org/docs/docs/publications/2010yearbook/P64-69_Kokal-Al_Kaabi.pdf
WPC	2015	Exploration & production in the marine environment, guidance from World Petroleum Council.
Ythan	2014	Ythan Field Development Environmental Statement, produced by Enquest

Appendix A
Onshore processes, technologies, risks and management - process, techniques, risk and management matrix

The table below has been developed in order to capture key information for onshore 'conventional' oil and gas extraction. It covers what the project team identified as the main processes and technologies applied (at a high level), potential environmental risks associated with these processes and a review of potential management measures. Following this, a conclusion is drawn on the level of risk with and without the specified management measures in place. This conclusion is formulated using judgement, and is hence open to interpretation depending on the particular types of field and oil and gas activities.

Processes/technologies: The main processes associated with oil and gas facilities, focusing on those with potential for environmental impacts (but not aiming for a comprehensive list of all processes).

Environmental aspect: An element of a process or technology that interacts with the environment. Environmental aspects can cause either positive or negative environmental impacts.

Expected management measures: Measures typically in place prevent, detect, control, or manage risks associated with the environmental hazard, or remediate their impacts.

Receptor: Living organisms, the habitats which support such organisms, or natural resources which are affected by environmental impacts.

Impacts: The change to the environment caused, directly or indirectly, by one or more environmental aspects.

Risk level: Determined by assessing the consequences (to what extent the receptor is being impacted) and likelihood (how likely it is that the identified impacts will occur, assuming that typical management measures are in place). Scoring as per the agreed matrix. A further column identifies the risk level without the specified risk management measures in place. This is not the same as an 'unmanaged' risk, as other design, etc. factors serve to help manage the risks.

Management measures: For the management measures identified, this considers the extent to which it is applied in contemporary practices.

Categories for main environmental risks/impacts assessed for onshore exploration and production:

- Groundwater contamination and other risks (includes induced seismicity)
- Surface water contamination
- Water resource depletion
- Releases to air (both local air quality and contributions to global emissions)
- Land take
- Biodiversity impacts
- Noise
- Visual impact
- Traffic
- Seismicity

The table draws on information from a variety of Environmental Statements (ESs) prepared as part of Environmental Impact Assessments (EIAs) conducted on the onshore industry (mainly in the UK). In addition, we have utilised internal expertise for the interpretation and assessment of environmental risks associated with exploration and production.

Potential uptake rates for measures have been estimated as either 'likely to be applied' or 'possible to be applied' using expert judgement. These qualitative indicators have also been translated to an approximate percentage of uptake (90% and 40% respectively), as per the approach used for shale gas in AMEC (2014). In the 2014 report the costs of implementing risk management measures fed into a quantitative impact assessment, therefore to avoid an overestimation of impacts for those measures which were not systematically used by all operators, costs were adjusted downward to reflect a (purely hypothetical) average level of uptake. Specifically, 10% of compliance costs was assumed for the measures that were considered to be *likely to be applied* (i.e. 90% uptake level) and 60% of costs for the measures considered to be *possible to be applied* (i.e. 40% uptake level). The percentage uptake figures, suggested by the Commission, were therefore only illustrative and were not intended to be predictors of actual uptake of any individual measure by operators.

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
Stage 1 Site identification & preparation	1. Identification of resource (Desk top study)	**1.1 Desk studies** of target area for favourable geological conditions, licensing	Not applicable	Desk based task - no specific risk identified so not considered further.	Not applicable	Not applicable	Not applicable	Not applicable	-
	2. Surveying	**2.1 General investigation:** - Aerial survey of land features e.g. satellite imagery, aircrafts, etc.	• **Releases to air**: Exhaust engines, GHG from aircraft • **Noise**: Motor noise from aircraft • **Visual impact**: Negligible since increased number of aircrafts for surveys is minimal	• **General**: Plan ahead. Required licences. • **Noise and releases to air**: Restrict number of flights for when it is necessary and follow flight plan. Noise abatement measures and air emission limits (ICAO). • **Noise**: Take into account seasonality for migrating birds.	• Migrating birds • Local residences • Atmosphere	• Noise affecting migrating birds • Air emissions from aircraft increasing air pollution to local residents. • Contribution to global emissions (climate change, sea acidification, etc.)	**Releases to air (local)**: Likelihood - Likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and only abate a proportion of emissions when they are adopted. **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted. **Noise**: Likelihood - Likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in aircraft noise.	**Releases to air (local)**: Likelihood - Likely, Consequence - slight, Risk: 4 low **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate) **Noise**: Likelihood - Likely, Consequence - slight, Risk: 4 low	Measures for low sulphur content of fuels in aircrafts and exhaust engines: Possible to be applied (40%)
		2.2 Geophysical testing/investigations:	• **Surface water**: Depending on method, it can lead to spillage or leakage if insufficient	• **General**: Plan ahead - aquifer protection and proper plugging. Establish	• Local fauna and flora • Local residences	• Loss of land from clearing of land	**Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low	**Surface water**: Likelihood - occasional,	Environmental planning: Possible to be applied (40%)

[1] For measures that are considered to be '*likely to be applied*', an approximate uptake level of 90% is assumed. For measures that are considered to be '*possible to be applied*' an approximate uptake level of 40% is assumed.

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
		- Land based seismic	plugging or management measures. E.g. Shot gun (dynamite) • **Releases to air**: Dust and exhaust emissions from survey equipment, exposed land and vehicles. • **Land take and biodiversity impacts**: Community displacement, loss of land and vegetation. Damage to local infrastructure • **Noise**: short-term from vehicles and machinery • **Visual impact**: Short-term impact of vehicles and machines • **Traffic**: Localised increase in traffic • **Seismicity**: Disturbance to wildlife and humans from vibrations or explosions.	baseline environmental aspect conditions (e.g. air, noise, groundwater, surface water, ecology and landscape). Establish monitoring measures during operations. • **Biodiversity impacts**: Use less intrusive seismic practices e.g. vibroseis vs. shotgun • **Noise**: Minimise engine and equipment use for necessary testing only. • **Air**: Fuel efficient generators and regular maintenance of vehicles and machines. • **Landtake**: take into account seasonality for migrating birds and fauna breeding seasons. Minimise landtake and use existing routes and already disturbed areas. • **Traffic:** Traffic impact assessment • **Seismicity:** Required licences. Use of low impact seismic techniques.	• Contaminated surface water bodies • Atmosphere	• Exposed land increase risk of surface runoff to surface water bodies. • Noise disturbance to fauna from machines • Contribution to global emissions (climate change, etc.)		Consequence - minor, Risk: 5 moderate	BAT seismic equipment: Possible to be applied (40%)
							Releases to air (local): Likelihood - Likely, Consequence – slight, Risk: 4 low	**Releases to air (local):** Likelihood – Highly Likely, Consequence – Slight, Risk: 5 moderate	
							Releases to air (global): Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	**Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	
							Land take: Likelihood – likely, Consequence – slight (short-term definite), Risk: 4 moderate. No change as much of the land take of operations is essential equipment.	**Land take**: Likelihood – likely, Consequence – slight (short-term definite), Risk: 4 moderate	
							Visual impact: Likelihood – likely (periodic), Consequence - slight, Risk: 4 low. No change as much of the visual presence of operations is essential equipment.	**Visual impact**: Likelihood – likely (periodic), Consequence - slight, Risk: 4 low	
							Biodiversity: Likelihood - Rare, Consequence – Slight, Risk: 2 low	**Biodiversity**: Likelihood – occasional, Consequence – Slight, Risk: 3 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							Noise: Likelihood - Likely, Consequence – Slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	**Noise**: Likelihood - Likely, Consequence – Slight, Risk: 4 low	
							Traffic: Likelihood – Likely, Consequence – slight (short-term definite), Risk: 4 low	**Traffic**: Likelihood – Highly likely, Consequence – slight (short-term definite), Risk: 5 moderate	
							Seismic: Likelihood – Highly likely, Consequence – slight (short-term definite), Risk: 4 low.	**Seismic**: Likelihood – Highly likely, Consequence – slight (short-term definite), Risk: 5 moderate	
		2.3 Development of conceptual model	Desk based task - no specific risk identified so not considered further.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-
	3. Exploratory drilling	**3.1 Baseline surveys** (ecology, hydrology, groundwater, community impact, etc.)	Investigative task	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-
		3.2 Mobilisation of drilling rig and **equipment** and people to the drill location	• **Surface water**: Surface runoff from spillages and leakage from machines and vehicles. • **Releases to air**: Exhaust and vehicle emissions • **Noise**: Low level noise and disturbance to local environment	Refer to measures listed for 2.2 Geophysical testing/investigations Further measures include: • **Traffic**: Proper planning of transportation route. • **Surface water**: Spill management	• Contaminated surface water bodies • Air emissions to local marine flora and fauna • Air emissions to local residence • Atmosphere	• Diesel contamination to surface water bodies affecting water habitats. • Additional air pollution from vehicles to surrounding area.	**Surface water**: Likelihood - rare, Consequence - slight, Risk: 2 low **Releases to air (local)**: Likelihood - Likely, Consequence - slight, Risk: 4 low. No change as measures may not be	**Surface water**: Likelihood - Occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local)**: Likelihood - Likely, Consequence - slight, Risk: 4 low	Environmental planning: Likely to be applied (90%) Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Traffic**: Increase of vehicles and traffic creating burden on existing roads.	• **Air and noise**: Good construction practices including on-site housekeeping practices. • **Releases to air**: Installation of emission control devices.		• Noise from vehicles disturbing local habitats and residents. • Contribution to global emissions (climate change, etc.)	adopted and only abate a proportion of emissions when they are adopted.		
							Releases to air (global): Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	**Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	
							Noise: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in drilling noise.	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low	
							Traffic: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low	
		3.3 Site preparation (e.g. site clearing, accessibility, infrastructure, etc.)	• **Surface water** : exposed land leading to pollution risk to surface runoff and erosion • **Releases to air**: Dust from exposed land. Exhaust emissions from vehicles and generators.	Refer to measures listed for 2.2 Geophysical testing/investigations Further measures include: • **General:** Waste management plan for construction and	• Loss of local flora and fauna • Loss of tourism • Industrial view for local residence/ community	• Oil and sediment contaminated surface water bodies affecting water habitats by destroying delicate	**Surface water**: Likelihood - rare, Consequence - minor, Risk:4 low	**Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate	Exclusion zones around drilling rig: Likely to be applied (90%) Maintenance programs for all
							Releases to air (local): Likelihood – likely (short-term definite),	**Releases to air (local)**: Likelihood – Highly likely (short-term	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Land take**: Land and vegetation clearing, excavation • **Visual impact**: Industrialisation of area – altered landscape • **Biodiversity impacts**: Loss of habitat and surface disturbances • **Noise**: Vehicle, machinery, generators intermittent or constant noise • **Traffic**: Increase in number of vehicles – burden on local access road capacity	operation. Effective site security. Site designed to avoid and contain spillages and leakages. • **Landtake**: Minimise and limit area to be cleared. Proper planning and use existing infrastructure if available • **Releases to air**: Regular maintenance and emission control devices on vehicles and machines.	• Landscape change • Contaminated surface water bodies • Air emissions to local marine flora and fauna • Air emissions to local residents • Atmosphere	ecosystems and changing diversity. • Land clearance leading to loss of vegetation and land for flora and fauna. Habitats destroyed. • Noise and traffic from machines affecting wildlife and local residents. • Contribution to global emissions (climate change, etc.)	Consequence - slight, Risk: 4 low	definite), Consequence - slight, Risk: 5 moderate	equipment: Likely to be applied (90%)
							Releases to air (global): Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	**Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	
							Land take: Likelihood – likely (short-term definite), Consequence - minor, Risk: 8 moderate	**Land take**: Likelihood – highly likely, Consequence - minor, Risk: 10 high	
							Visual impact: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low. No change as much of the visual presence of operations is essential equipment	**Visual impact**: Likelihood – Likely, Consequence - slight, Risk: 4 low	
							Biodiversity: Likelihood – Rare, Consequence - minor, Risk: 4 low	**Biodiversity**: Likelihood – Occasional, Consequence - minor, Risk: 6 moderate	
							Noise: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	**Noise**: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							Traffic: Likelihood – Likely (short-term definite), Consequence – slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood – Likely (short-term definite), Consequence – slight, Risk: 4 low	
Stage 2 Well design, construction and completion	4. Exploration Well Construction	**4.1 Well pad construction**	• **Groundwater and surface water contamination**: Spillage and release onto surface and seepage into groundwater. • **Releases to air**: GHG from exhaust, machinery, generator and dust from construction material, exposed land • **Land take, visual and Biodiversity impacts**: Removal of vegetation and loss of land to access road, construction area, storage area. Industrialised area. Conventional oil and gas drilling typically require 1 well per pad. Situated in areas with high value or near residential areas. • **Noise**: Construction noise. Less noisy compared to drilling. • **Traffic**: Increase traffic during construction period (short-term)	• **General**: Required licences. Effective site security. Good construction practices. Consideration of decommissioning and restoration in site selection and preparation. • **Environmental Impact Assessment[2]**: Establish baseline environmental aspect conditions (e.g. air, noise, groundwater, surface water ecology and landscape). Review of the potential impact on environment. Waste management plan. Establish monitoring measures for environmental aspects during operation. • **Groundwater and surface water contamination**:	• Flora and fauna (include any protected species) • Site of scientific interest • Atmosphere	• Any spillages from machines and runoff from construction materials into surface water bodies and contaminating it. This can lead to habitat and biodiversity loss in the immediate vicinity. • Increased air pollution affecting local area. • Land clearance leading to further habitat and biodiversity loss as well as increased erosion of the land. • Contribution to global emissions	**Groundwater**: Likelihood – rare, Consequence – moderate, Risk: 6 Moderate **Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local)**: Likelihood - likely, Consequence - minor, Risk: 8 moderate. No change as measures may not be adopted and only abate a proportion of emissions when they are adopted. **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion	**Groundwater**: Likelihood – Occasional, Consequence – moderate, Risk: 9 High **Surface water**: Likelihood - likely, Consequence - minor, Risk: 8 moderate **Releases to air (local)**: Likelihood - likely, Consequence - minor, Risk: 8 moderate **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	Environmental planning: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Use of bunding/protected skids/tote tanks for chemical storage: Likely to be applied (90%)

[2] An EIA is mandatory if the development is expected to produce more than 500t oil or 500,000m^3 gas per day (EIA Directive 2011/92/EU amended by Directive 2014/52/EU). For projects below this threshold, surface industrial installations for petroleum and gas extraction, and deep drillings, the competent authority screens these projects to determine whether they are likely to have a significant adverse effect on the environment. In the event that the competent authority does not deem it necessary to conduct an EIA in order to grant the permit, then associated risk management measures may not be applied. However, this is only for projects where environmental risk has been deemed to be low enough for these measures not be required.

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
				Spill management procedure. • **Landtake**: Minimise and limit area to be cleared. Site designed to avoid and contain spillages and leakages. Proper planning and use existing infrastructure if available • **Releases to air**: Regular maintenance of vehicles and machines. Emission control devices. Fuel efficient generators and vehicles. Cover of dusty construction materials.		(climate change, etc.)	of emissions when they are adopted.		
							Biodiversity impact: Likelihood – Occasional (Short-term definite), Consequence – Slight (individual installation), Risk: 3 low	**Biodiversity impact**: Likelihood – Occasional (Short-term definite), Consequence – Minor (individual installation), Risk: 6 moderate	
							Visual impact: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low. No change as much of the visual presence of operations is essential equipment	**Visual impact**: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low	
							Noise: Likelihood - likely, Consequence – slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in equipment and vehicle noise.	**Noise**: Likelihood - likely, Consequence – slight, Risk: 4 low	
							Traffic: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low	
		4.2 Rig installation	• **Releases to air**: Dust and GHG emissions from vehicles and machinery • **Noise**: Construction noise	Refer to 4.1 well pad construction for management measures.	• Local residence • Local flora and fauna • Atmosphere	• Machines and vehicles producing further air	**Releases to air (local)**: Likelihood - likely, Consequence - slight, Risk: 4 low	**Releases to air (local)**: Likelihood - highly likely, Consequence - slight, Risk: 5 moderate	Maintenance programs for all equipment: Likely to be applied (90%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Traffic**: Increased traffic over construction period (short-term)			pollution into the area • Short-term noise from moving vehicles and machines affecting wildlife. • Contribution to global emissions (climate change, etc.)	**Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	**Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	
							Noise: Likelihood - likely, Consequence – slight, Risk: 4 low	**Noise**: Likelihood – Highly likely, Consequence – slight, Risk: 5 moderate	
							Traffic: Likelihood - likely, Consequence - slight, Risk: 4 low	**Traffic**: Likelihood – Highly likely, Consequence - slight, Risk: 5 moderate	
		4.3 Drilling of vertical or deviated wells	• **Groundwater contamination**: Leakage of chemicals and seepage of oil and gas from inadequate preparation and well blowouts. • **Surface water contamination risks**: Surface run off from surface spillage and leakage of chemicals, oil, contaminated sediments, drill muds and fluids, drill cuttings and well blowouts • **Water resource depletion**: Used for drilling and workers - Some pressure on local water source	Refer to 4.1 well pad construction for management measures. Refer to 11.2 site operations for measures related to accidental spills. Further measures include: • Well safety controls and monitoring • Water requirement assessed and treated or produced water reused. • Install noise screening such as noise barrier/enclosure	• Local flora and fauna • Local residence/ communities • Groundwater aquifers • Surface water bodies • Atmosphere	• Chemical spill, mud, cement, and leakages into groundwater and contaminating it • Chemical spill, mud cuttings and leakages into surface water. • Large quantities of air emissions released into the air affecting flora growth, fauna and local residents' health.	**Groundwater**: Likelihood – rare, Consequence – moderate, Risk: 6 moderate	**Groundwater**: Likelihood – occasional, Consequence – moderate, Risk: 9 high	Environmental planning: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Blow-out preventer: Likely to be applied (90%) Valve systems including SSIVs, choke and kill systems, and X-mas tree: Likely to be applied (90%)
							Surface water: Likelihood - rare , Consequence - moderate, Risk: 6 moderate	**Surface water**: Likelihood - occasional, Consequence - major, Risk: 12 high	
							Water resource depletion: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as water usage remains very high therefore	**Water resource depletion**: Likelihood - likely, Consequence - slight, Risk: 4 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Releases to air**: Release of trapped gas, well blowout, VOCs, emissions from flaring, CO2 emissions from generators and emissions from construction equipment and vehicles. • **Biodiversity impacts**: Risk to habitat and species due to disturbances to the environment, spillages, air emissions, miss-use of chemicals, constant loud noise. • **Noise**: High noise level occurring continuously for a period of time. Impact very significant • **Traffic**: Large number of vehicles potentially loading large burden on local road infrastructure The risks and impacts of major and minor accidental spills are categorised in stage 3 production. They also apply to drilling operations, therefore for a categorisation of risks associated with these incidents during drilling, see 11.2 site operations.			• Continuous noise over a period of time which will affect surrounding flora and fauna and local residents. • Visual impact disturbance on local residents and wildlife due to the strong lights at night. • Increased traffic may overload local access routes capacity. • Contribution to global emissions (climate change, etc.) The risks and impacts of major and minor accidental spills are categorised in stage 3 production. They also apply to drilling operations, therefore for a categorisation of risks associated with these incidents during drilling, see 11.2 site operations.	measures have little impact. **Releases to air (local):** Likelihood - Occasional, Consequence - minor, Risk: 6 moderate **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate) **Biodiversity**: Likelihood – rare, Consequence - Slight, Risk: 2 low **Noise**: Likelihood - Likely, Consequence - Slight, Risk: 4 low **Traffic**: Likelihood – likely (short-term definite), Consequence – slight, Risk: 4 low	**Releases to air (local)**: Likelihood - Likely, Consequence - Moderate, Risk: 12 high **Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (High) **Biodiversity**: Likelihood – likely, Consequence - Slight, Risk: 4 low **Noise**: Likelihood – Highly Likely, Consequence - Slight, Risk: 5 moderate **Traffic**: Likelihood – Highly likely (short-term definite), Consequence – slight, Risk: 5 moderate	Well pressure monitoring: Likely to be applied (90%) Emergency plans, including spill clean-up: Likely to be applied (90%) Use of bunding/protected skids/tote tanks for chemical storage: Likely to be applied (90%) Quick release valve systems: Possible to be applied (40%) Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%) Noise abatement measures: Possible to be applied (40%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
		4.4 Drill cutting management	• **Groundwater contamination**: Seepage of chemicals and oil from untreated drill cuttings depending on disposal method. • **Surface water contamination risks**: Surface run off from surface spillage and leakage of chemicals, oil, contaminated sediments, untreated drill cuttings. • **Releases to air**: VOCs releases from contaminated drill cutting storage and CO2 emissions from generators and emissions from collection vehicles or treatment vehicles. • **Traffic**: Increased number of vehicles potentially loading large burden on local road infrastructure	Refer to 4.1 well pad construction and waste management plan for general management measures. Further measures include: • Drill cuttings separated from the drilling mud and collected in skips and taken offsite as soon as reasonably practicable for recycling or recovery by an authorised waste contractor. • Containers of drilled cuttings should not be over filled and precautions taken to prevent spillage. • All waste collection areas and deposit and storage of oil based drilling muds will have a secondary containment. • Continuous supervision of the cuttings skips when active mud management is in operation. • Segregation of oil based mud contaminated cuttings • Segregation of cuttings contaminated with hydrocarbons from the formation encountered • Spill management procedure in places • Hazardous chemicals stored in designated areas	• Local flora and fauna • Local residence/ communities • Groundwater aquifers • Surface water bodies • Atmosphere	• Leakage of chemicals, additives and contaminated (oil) drill cuttings into groundwater and contaminating it • Chemical spill, mud cuttings and leakages into surface water. • Increased traffic may overload local access routes capacity. • Contribution to global emissions (climate change, etc.)	**Groundwater**: Likelihood – rare, Consequence – Slight, Risk: 2 low **Surface water**: Likelihood - rare, Consequence - moderate, Risk: 6 moderate **Releases to air (local):** Likelihood - Occasional, Consequence - minor, Risk: 6 moderate **Releases to air (global):** Likelihood: Likely Consequence: Slight Risk: 4 low **Traffic**: Likelihood – likely (short-term definite), Consequence – slight, Risk: 4 low	**Groundwater**: Likelihood – rare, Consequence – minor, Risk: 4 low **Surface water**: Likelihood - occasional, Consequence - major, Risk: 12 high **Releases to air (local)**: Likelihood - Likely, Consequence - minor, Risk: 8 moderate **Releases to air (global):** Likelihood: Likely Consequence: Minor Risk: 8 moderate **Traffic**: Likelihood – Highly likely (short-term definite), Consequence – slight, Risk: 5 moderate	Environmental planning: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Emergency plans, including spill clean-up: Likely to be applied (90%) Use of bunding/protected skids/tote tanks for chemical storage: Likely to be applied (90%) Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
				with bunding and drain systems to contain leaks. • Chemical selection procedure prioritising: ○ Lowest toxicity ○ Lowest persistence ○ Lowest bioaccumulation potential					
		4.5 Cementing and Casing	• **Groundwater contamination**: Poor cement job or damage to casing will lead to leakage or seepage of chemicals or hydrocarbon impacted material. • **Surface water:** Insufficient casing leading to leakages of chemicals and hydrocarbon impacted material – surface runoff, interaction between groundwater and surface water. • **Water resource depletion**: Quantities of water for cementing • **Releases to air**: Dust emissions from cementing, machinery and generators	Refer to 4.1 well pad construction for management measures. Further measures include: • Calcium chloride to accelerate the setting of cement. • Integrity testing (including independent review) of wells to ensure proper construction and containment.	• Surface water bodies • Groundwater aquifers • Local residence/ communities	• Cracks in the casing can allow leakage of chemicals, drill cuttings, oil impacted soils into groundwater. • If not careful during cementing works or during use of chemicals, this can lead to spills and runoff into surface water bodies. • Dust from construction works can create immediate dust particles increasing air pollution to flora and fauna fecundity and local residents' health.	**Groundwater**: Likelihood – rare, Consequence – Moderate, Risk: 6 moderate **Surface water**: Likelihood – rare, Consequence – Moderate, Risk: 6 moderate **Releases to air (local)**: Likelihood - Likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and only abate a proportion of emissions when they are adopted. **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	**Groundwater**: Likelihood – occasional, Consequence – Moderate, Risk: 9 high **Surface water**: Likelihood – occasional, Consequence – Major, Risk: 12 high **Releases to air (local)**: Likelihood - Likely, Consequence - slight, Risk: 4 low **Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (High)	-

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							Water resource depletion: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as water usage remains very high therefore measures have little impact.	**Water resource depletion**: Likelihood - likely, Consequence - slight, Risk: 4 low	
		4.6 well stabilisation	• **Groundwater and surface water contamination**: insufficient plugging leading to leakage and seepage • **Releases to air**: venting of trapped gas and emissions of VOCs	Refer to 4.1 well pad construction for management measures. Further measures include: • Flares to reduce emissions at exploration stage (where not connected to gas network)	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Local residence/ communities • Atmosphere	• Oil impact soils may leak out of insufficient plugging • Air pollution to local residents' health and flora and fauna fecundity from flaring. • Contribution to global emissions (climate change, etc.)	**Groundwater**: Likelihood – rare, Consequence – Moderate, Risk: 6 moderate. No change because measures cannot reduce the likelihood of contamination below rare.	**Groundwater**: Likelihood – rare, Consequence – Moderate, Risk: 6 moderate	Flare tip design and metering: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%)
							Surface water: Likelihood – Rare, Consequence – minor, Risk: 4 low. No change because measures cannot reduce the likelihood of contamination below rare.	**Surface water**: Likelihood – Rare, Consequence – minor, Risk: 4 low	
							Releases to air (local): Likelihood - Likely, Consequence - minor, Risk: 8 Moderate	**Releases to air (local):** Likelihood – Highly Likely, Consequence - minor, Risk: 10 High	
							Releases to air (global): Likelihood: Highly Likely Consequence: Slight Risk: 5 (Moderate)	**Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (High)	
	5. Well testing	**5.1 Well Test** (well may be					**Releases to air (local)**: Likelihood - Likely,	**Releases to air (local)**: Likelihood - Likely,	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
		temporarily plugged and testing carried out at a later point)	• **Releases to air**: Flaring of trapped gas or emissions of VOCs and dust from exploratory well.	Refer to 4.1 well pad construction for management measures.	• Local residence/ communities • Atmosphere	• Air pollution to local residents' health and flora and fauna fecundity from flaring. • Contribution to global emissions (climate change, etc.)	Consequence - minor, Risk: 8 Moderate. No change as measures may not be adopted and only abate a proportion of emissions when they are adopted. **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	Consequence - minor, Risk: 8 Moderate **Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (high)	Flare tip design and metering: Likely to be applied (90%)
		5.2 Management of produced water from exploratory wells	• **Groundwater contamination**: Long termed contamination from spills seeping from surface • **Surface water**: Leakage and spills onto surface and subsequent surface runoff to water bodies. • **Releases to air**: hydrocarbon release to air from produced water treatment • **Biodiversity impacts**: Spills to surface may change sediment characteristic. Produced water high in salt, oil/grease, chemicals and maybe NORM. – (Note: refer to drilling) • **Noise**: Generator from treating produced water • **Traffic**: Produced water transportation	Refer to stage 1 and stage 2 - 4.1 well pad construction for management measures. Further measures include: • **General**: Specific management approaches (following the required treatment processes) include: Recycling, discharge to water course, evaporation, infiltration or deep well injection	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Atmosphere	• If containment is breached, contaminated groundwater aquifers may affect local water resources. Contaminated surface water may affect local water habitat, flora and fauna. • Increased air pollution into the surrounding areas from the water treatment plant. • The toxic nature of produced water can change surrounding flora diversity. • Noise from the treatment plant is low but persistent	**Groundwater**: Likelihood – Rare, Consequence – minor, Risk: 4 low **Surface water**: Likelihood – Rare, Consequence – minor, Risk: 4 low **Releases to air (local)**: Likelihood – Rare, Consequence – Slight, Risk: 2 low **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate) **Biodiversity impact**: Likelihood – Rare, Consequence – Slight, Risk: 2 low	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate **Surface water**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate **Releases to air (local):** Likelihood – Occasional, Consequence – Slight, Risk: 3 low **Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (high) **Biodiversity impact**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate	Environmental planning: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Use of bunding/protected skids/tote tanks for chemical storage: Likely to be applied (90%) Use of PLONOR chemicals: Likely to be applied (90%) Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
						which can irritate local residents or fauna. • Contribution to global emissions (climate change, etc.)	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low	
							Traffic: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low	
		5.3 Revised conceptual model and resource estimate	Desk based task - no specific risk identified so not considered further.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-
		5.4 Assessment - Evaluate technical and economic viability for the whole project and develop plans for production	Desk based task - no specific risk identified so not considered further.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-
	6. Well completion	**6.1 Well completion** - screens, valves, (completed items), etc.	• **Groundwater and surface water contamination**: improper completion leading to leakage and seepage • **Releases to air**: Flaring and venting of gas and VOCs.	Refer to stage 1 and stage 2 - 4.1 well pad construction for management measures. Further measures include: • **General:** Deployment of key elements to maintain	• Local flora and fauna • Surface water bodies • Groundwater aquifers	• Improper completion can contaminate surface water bodies leading to	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate	**Groundwater**: Likelihood – Occasional, Consequence – moderate, Risk: 9 high	Flare tip design and metering: Likely to be applied (90%) Maintenance programs for all
							Surface water: Likelihood - Rare,	**Surface water**: Likelihood -	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Land take and visual impact**: Refer to drilling, a small proportion may be returned to prior use. • **Biodiversity impacts:** refer to drilling • **Noise:**	well safety[3]. Avoid excess (e.g. cement works) • **Release to air:** Installation of required emissions control devices on drilling and associated equipment. Minimise engine and equipment use. • **Groundwater and surface water contamination:** Good construction practices for preventing dust, leaks and spills.	• Local residence/ communities • Atmosphere	habitat and biodiversity loss. • Flaring increases air pollution affecting local resident's health • Contribution to global emissions (climate change, etc.)	Consequence - slight, Risk: 2 low **Releases to air (local)**: Likelihood: Occasional Consequence: Slight Risk: 3 (low) **Releases to air (global):** Likelihood: High Likely Consequence: Slight Risk: 5 (moderate) **Noise**: Likelihood – likely (short-term definite), Consequence – slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local)**: Likelihood: Highly Likely Consequence: Minor Risk: 10 (High) **Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (high) **Noise**: Likelihood – likely (short-term definite), Consequence – slight, Risk: 4 low	equipment: Likely to be applied (90%) BAT drilling equipment: Possible to be applied (40%)
Stage 3 Development and production	7. Field development design (not all necessarily required)	**7.1 Field development** (Planning and design)**:** - Field development concept - Front end engineering design - Detailed design	Desk based task - no specific risk identified so not considered further.	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-

[3] Such as blowout preventers, pressure & temperature monitoring and shutdown systems, fire and gas detection and continuous monitoring for leaks and release of gas and liquids, isolate underground source of drinking water prior to drilling, ensure micro-annulus is not formed, casing centralizers to centre casing in hole, select corrosive resistant alloys and high strength steel, fish back casing, maintain appropriate bending radius, triple casing, isolation of the well from aquifers.

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
	8. Construction and installation	**8.1 Implementation of development plan** - Increased site clearing - Extra access (i.e. roads, infrastructure)	Refer to site preparation. • Assumption: Scale of process increases	Refer to management measures outlined in sub-stage 4 of site preparation but with a larger scope. Further measures include: • **General:** Required licences. Environmental impact assessment[4] (e.g. baseline environmental aspect conditions, pre-drill tests such as water tests, minimising assessed impacts, monitoring measures for environmental aspects during operations). Waste management plan. Site security. Good construction practices. Consideration of decommissioning and restoration in site selection and preparation. • **Surface water:** Site designed to avoid and contain spillages and leakages. Oil-water separators in drainage. Easy access to spill kits. Spill management plan. • **Traffic**: Traffic impact assessment. • **Releases to air**: Installation of required emissions control devices on drilling and associated	• Local flora and fauna • Surface water bodies • Local residence/ communities • Atmosphere	• Further oil and sediment contaminated surface water bodies affecting water habitats by destroying delicate ecosystems and changing diversity. • Increased land clearance leading to further loss of vegetation and land for flora and fauna. Habitats destroyed. • Increased noise and traffic from machines affecting wildlife and local residents. • Contribution to global emissions (climate change, etc.)	**Surface water**: Likelihood – Rare, Consequence – minor, Risk: 4 low	**Surface water**: Likelihood – occasional, Consequence – minor, Risk: 6 moderate	Refer to site preparation in Stage 3
							Releases to air (local): Likelihood – likely (short-term definite), Consequence - slight, Risk: 4 low. No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	**Releases to air (local)**: Likelihood – likely (short-term definite), Consequence - slight, Risk: 4 low	
							Releases to air (global): Likelihood – highly likely, Consequence - slight, Risk: 5 moderate	**Releases to air (global)**: Likelihood – Highly likely, Consequence - Minor, Risk: 10 high	
							Land take: Likelihood – likely (short-term definite), Consequence – moderate (wider scale), Risk: 12 high. No change as much of the land take of operations is essential equipment.	**Land take**: Likelihood – likely (short-term definite), Consequence – moderate (wider scale), Risk: 12 high	
							Visual impact: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low. No change as much of the visual presence of	**Visual impact**: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low	

[4] See footnote 2.

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
				equipment. Fuel efficient generators. Cover dusty construction materials. Frequent watering of dry, exposed areas. • **Landtake**: Minimising land take and use of existing routes and already disturbed areas. Site chosen at exploration and development planning to encourage natural rehabilitation.			operations is essential equipment.		
							Biodiversity: Likelihood – rare, Consequence - Slight, Risk: 2 low	**Biodiversity**: Likelihood – occasional, Consequence - Slight, Risk: 3 low	
							Noise: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	**Noise**: Likelihood – Likely (periodic), Consequence - slight, Risk: 4 low	
							Traffic: Likelihood – Likely (short-term definite), Consequence – slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood – Likely (short-term definite), Consequence – slight, Risk: 4 low	
	9. Hook-up and commissioning	**9.1 Well commissioning** - Completed well hook-up - Pre-commissioning - Commissioning	• **Groundwater and Surface water contamination**: contamination from hydrostatic testing water availability, chemical dosing, water disposal • **Waste resource depletion**: water used to conduct various testing such as hydrostatic testing • **Releases to air**: Flaring from start up, maintenance or upset	Refer to management measures as outlined in stage 1 and stage 2 of the oil and gas processes and technologies. Further measures include: • **General**: Deployment of techniques to maintain well safety. • **Groundwater and surface water**: Erosion protection, runoff control and sediment interception for controlled discharge of	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Local residence/ communities • Atmosphere	• Toxic chemical spill from hydrostatic testing can lead to permanent loss of plant and habitat. Clean up may be expensive. • Further burden on local water resource capacity. However will be short-term. The water can be	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate	**Groundwater**: Likelihood – occasional, Consequence – moderate, Risk: 9 high	Flare tip design and metering: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Bunding, protected skids, totes: Likely to be applied (90%)
							Surface water: Likelihood - Rare, Consequence - minor, Risk: 4 low	**Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate	
							Water resource depletion: Likelihood - Rare, Consequence - Slight, Risk: 2 low. No change as water usage	**Water resource depletion**: Likelihood - Rare, Consequence - Slight, Risk: 2 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Biodiversity impacts**: leakage and spillage of harmful substances will impact flora and fauna. • **Noise**: Noise from machinery and generators	testing fluid. Pipeline cleaning with cleaning pigs before hydrostatic testing.		replenished after a period of time. • Release of air pollution affecting local resident's health • Low and persistent noise from machines may be an irritant to nearby residents. • Contribution to global emissions (climate change, etc.)	remains very high therefore measures have little impact.		
							Releases to air (local): Likelihood - occasional, Consequence – Slight, Risk: 3 low	**Releases to air (local and global)**: Likelihood - likely, Consequence – Slight, Risk: 4 low	
							Releases to air (global): Likelihood – Highly Likely, Consequence – Slight, Risk: 5 moderate	**Releases to air (global)**: Likelihood – highly likely, Consequence – Minor, Risk: 10 high	
							Biodiversity: Likelihood - Rare, Consequence - Slight, Risk: 2 low	**Biodiversity**: Likelihood - Occasional, Consequence - Slight, Risk: 3 low	
							Noise: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in equipment noise.	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low	
	10 Development drilling- if required, once field development in place	**10.1 Development drilling** (further development, if required) - Small drilling field - Large drilling field	• Refer to exploration drilling. • Cumulative impacts • Accidental spillages (Refer to Drilling of vertical or deviated wells in Stage 4)	Refer to management measures outlined for 8.1 Implementation of development plan. Further measures include: • **General**: Re-injection of gas or vapour recovery (green measures). Good housekeeping practices (including keeping working areas tidy and clean, regularly removing waste	• Local flora and fauna • Local residence/ communities • Groundwater aquifers • Surface water bodies • Atmosphere	• Chemical spill, mud, cement, and leakages into groundwater and contaminating it • Chemical spill, mud cuttings and leakages into surface water. • Large quantities of air emissions released into the air affecting flora growth, fauna and	**Groundwater**: Likelihood – rare, Consequence – moderate, Risk: 6 moderate	**Groundwater**: Likelihood – occasional, Consequence – moderate, Risk: 9 high	Refer to Drilling of vertical or deviated wells in Stage 4
							Surface water: Likelihood – Rare, Consequence – minor, Risk: 4 low	**Surface water**: Likelihood – occasional, Consequence – moderate, Risk: 9 High	
							Water resource depletion: Likelihood – likely, Consequence - Slight, Risk: 4 low. No change	**Water resource depletion**: Likelihood – likely, Consequence - Slight, Risk: 4 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
				materials and storing items safely). • **Groundwater**: Implementation of local groundwater protection policies and management plans (permit conditions). Appropriate drilling fluids i.e. water based muds (WBMs) rather than oil based muds (OBMs).		local residents' health. • Continuous noise over a period of time which will affect surrounding flora and fauna and local residents. • Visual impact disturbance on local residents and wildlife due to the strong lights at night. • Increased traffic may overload local access routes capacity. • Contribution to global emissions (climate change, etc.)	as water usage remains very high therefore measures have little impact.		
							Releases to air (local): Likelihood - occasional, Consequence - slight, Risk: 3 low	**Releases to air (local)**: Likelihood - likely, Consequence - slight, Risk: 4 low	
							Releases to air (global): Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	**Releases to air (global):** Likelihood: High Likely Consequence: Minor Risk: 10 (high)	
							Land take: Likelihood – highly likely, Consequence - minor, Risk: 10 high. No change as much of the land take of operations is essential equipment.	**Land take**: Likelihood – highly likely, Consequence - minor, Risk: 10 high	
							Visual impact: Likelihood – highly likely, Consequence – moderate, Risk: 15 very high. No change as much of the visual presence of operations is essential equipment.	**Visual impact**: Likelihood – highly likely, Consequence – moderate, Risk: 15 very high	
							Biodiversity: Likelihood – Rare, Consequence - minor, Risk: 4 low	**Biodiversity**: Likelihood – occasional, Consequence - minor, Risk: 6 moderate	
							Noise: Likelihood - likely, Consequence – Slight, Risk: 4 low	**Noise**: Likelihood – Highly likely, Consequence – Slight, Risk: 5 moderate	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							Traffic: Likelihood – likely, Consequence – slight, Risk: 4 low	**Traffic**: Likelihood – Highly likely, Consequence – slight, Risk: 5 moderate	
	11. Hydrocarbon production - Hydrocarbon extraction and processing	**11.1 Crude Oil & Gas Processing** - Operation of plant and process equipment and maintenance activities Typical three phase separation: - Oil - Gas - Water	• **Surface water contamination**: discharge of produced water • **Releases to air**: Flaring of produced gas, emissions from machinery, equipment and generators. • **Land take and visual impact**: Area required to install treatment facility (taken into account during Implementation of development plan) • **Biodiversity:** Accidental spill affecting vegetation fecundity since pH and characteristics has changed. (taken into account during Implementation of development plan) • **Noise**: Noise from machinery and generators • **Traffic**: Increase traffic from vehicles collecting "offtakes" on site	Refer to management measures outlined for 8.1 Implementation of development plan. Further measures include: • Implementation of remedial measures if well failure occurs. • Deployment of key elements to maintain well safety. • Implementation of process control systems, ICT infrastructure and safety instrumented systems. • Gas capture • Produced water capture	• Local flora and fauna • Surface water bodies • Local residence/ communities • Local traffic infrastructure • Atmosphere	• Air pollution from escaping gas and flaring affecting local residents' health • Oil and other chemicals runoff into surface water bodies can lead to loss of biodiversity and habitat. • Accidental spill can lead to loss of vegetation, loss of habitat and biodiversity. • Long term traffic affecting local access road capacity and noise to local residents. • Contribution to global emissions (climate change, etc.)	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate **Surface water**: Likelihood – Rare, Consequence - minor, Risk: 4 low **Releases to air (local)**: Likelihood – Occasional (periodic), Consequence - minor, Risk: 6 moderate **Releases to air (global):** Likelihood: occasional Consequence: moderate Risk: 9 (High) **Noise**: Likelihood - occasional, Consequence - slight, Risk: 3 low **Traffic**: Likelihood – likely (periodic), Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures	**Groundwater**: Likelihood – occasional, Consequence – moderate, Risk: 9 High **Surface water**: Likelihood – occasional, Consequence - moderate, Risk: 9 High **Releases to air (local)**: Likelihood – Likely (periodic), Consequence - moderate, Risk: 10 high **Releases to air (global):** Likelihood: Likely Consequence: moderate Risk: 12 (High) **Noise**: Likelihood - Likely, Consequence - slight, Risk: 4 low **Traffic**: Likelihood – likely (periodic), Consequence - slight, Risk: 4 low	Flare tip design and metering: Likely to be applied (90%) Leak detection and repair programmes: Likely to be applied (90%) Process design for gas to avoid need for venting: Likely to be applied (90%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							result in only a minor reduction.		
		11.2 Site operations The likelihood of accidental spillages or release may increase when the site is located in rougher terrain and more extreme climates. This is because there is greater stress put on operating and containment equipment and lower margins for operator error during production.	Major events such as major well blowouts – catastrophic incidences that requires assistance from third party resources: The likelihood of accidental spillages may increase when the rig is situated in extreme climates, has more severe process conditions such as higher temperatures and pressures, larger and more complex facilities, inhospitable regimes and greater financial and resource challenges as competition increases. This is because there is greater stress put on containment equipment and lower margins for operator error during production. • **Groundwater and surface water contamination**: mass leakage of liquids (hydrocarbon/chemical/mud/ cement) leading to long term contamination • **Releases to air**: Accidental and sudden release of hydrocarbon related substances damaging local air quality and contributing to climate change.	Primary well control Use of blow-out preventer Valve assembly systems to manage flow of material and prevent loss to surrounding environment. This can include X-mas tree assemblies, Choke and kill systems, etc. (Mariner, Kew, & Edradour) Well pressure monitoring (well management) Emergency plans and training including spill clean-up procedures and if necessary specialist spill response operators. Spill clean-up resources	• Local flora and fauna • Local residence/ communities • Groundwater aquifers • Surface water bodies • Atmosphere	• Significant quantities of chemical/oil/gas spill, mud and cement leakages or spillages into groundwater and contaminating it • Significant quantities of chemical/oil/gas spill and mud cuttings leakages and spillages into surface water. • Significant quantities of air emissions released into the air affecting flora growth, fauna and local residents' health. Contribution to global emissions (climate change, etc.)	**Groundwater**: Likelihood – rare, Consequence – catastrophic, Risk: 10 high **Surface water**: Likelihood - rare , Consequence - catastrophic, Risk: 10 high **Releases to air (local and global):** Likelihood - rare, Consequence - major, Risk: 8 Moderate **Biodiversity**: Likelihood - Rare, Consequence - Catastrophic, Risk: 10 High	**Groundwater**: Likelihood – occasional, Consequence – Catastrophic, Risk: 15 very high **Surface water**: Likelihood - occasional, Consequence - Catastrophic, Risk: 15 very high **Releases to air (local and global)**: Likelihood - occasional, Consequence - Major, Risk: 12 high **Biodiversity**: Likelihood - occasional, Consequence - Catastrophic, Risk: 15 Very High	Environmental planning: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Blow-out preventer: Likely to be applied (90%) Valve systems including SSIVs, choke and kill systems, and X-mas tree: Likely to be applied (90%) Well pressure monitoring: Likely to be applied (90%) Emergency plans, including spill clean-up: Likely to be applied (90%) Use of bunding/protected skids/tote tanks for chemical storage: Likely to be applied (90%) Quick release valve systems: Possible to be applied (40%)
			Minor events such as containment failures etc.**:**	Primary well control Use of blow-out preventer	• Local flora and fauna	• Large quantities of chemical/oil/gas	**Groundwater**: Likelihood – rare,	**Groundwater**: Likelihood – occasional,	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			The likelihood of accidental spillages or sudden releases may increase when the rig is situated in extreme climates, has more severe process conditions such as higher temperatures and pressures, larger and more complex facilities, inhospitable regimes and greater financial and resource challenges as competition increases. This is because there is greater stress put on containment equipment and lower margins for operator error during production. • **Groundwater and surface water contamination**: leakage of liquids (hydrocarbon/chemical/mud/ cement) leading to contamination • **Releases to air**: Accidental and sudden release of hydrocarbon related substances damaging local air quality and contributing to climate change.	Valve assembly systems to manage flow of material and prevent loss to surrounding environment. This can include X-mas tree assemblies, Choke and kill systems, etc. (Mariner, Kew, & Edradour) Well pressure monitoring (well management) Emergency plans and training including spill clean-up procedures and if necessary specialist spill response operators. Spill clean-up resources	• Local residence/ communities • Groundwater aquifers • Surface water bodies • Atmosphere	spill, mud and cement leakage or spillages into groundwater and contaminating it • Large quantities of chemical/oil/gas spill and mud cuttings leakages and spillages into surface water. • Large quantities of air emissions released into the air affecting flora growth, fauna and local residents' health. • Contribution to global emissions (climate change, etc.)	Consequence – major, Risk: 8 moderate **Surface water**: Likelihood - rare , Consequence - major, Risk: 8 moderate **Releases to air (local):** Likelihood - rare , Consequence - minor, Risk: 4 low **Biodiversity**: Likelihood - rare , Consequence - major, Risk: 8 moderate	Consequence – major, Risk: 12 high **Surface water**: Likelihood - occasional, Consequence - major, Risk: 12 high **Releases to air (local)**: Likelihood - occasional, Consequence - Moderate, Risk: 9 moderate **Biodiversity**: Likelihood - occasional, Consequence - major, Risk: 12 High	Blow-out preventer: Likely to be applied (90%) Valve systems including SSIVs, choke and kill systems, and X-mas tree: Likely to be applied (90%) Well pressure monitoring: Likely to be applied (90%) Emergency plans, including spill clean-up: Likely to be applied (90%)
		11.3 Well workover – Conducted during monitoring and maintenance of completed wells. Well workovers, or interventions,	• **Surface water:** Discharge of chemicals used during well workovers	Refer to management measures outlined for 8.1 Implementation of development plan. Further measures include: • Implement management of wellbore maintenance in accordance with waste management procedures, in particular, deploy	• Local flora and fauna	• Oil and other chemicals runoff into surface water bodies can lead to loss of biodiversity and habitat.	**Surface water**: Likelihood – Rare, Consequence - minor, Risk: 4 low	**Surface water**: Likelihood – Occasional, Consequence - minor, Risk: 6 moderate	Use of PLONOR chemicals: Likely to be applied (90%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
		are performed by inserting tools in wellbores to conduct maintenance or remedial actions. Important terms include acidizing, fishing, pulling tool, squeeze, stripping and well servicing.		sediment interception, surface water protection and runoff control.					
		11.4 Process treatment systems - Produced water collection and management	• **Groundwater**: long term contamination of surface spills and leakages • **Surface water**: Contamination of surface runoff of spills and leakages • **Release to air**: inadequate treatment or measure in place for emissions capture from process water treatment • **Releases to air**: hydrocarbon release to air from produced water treatment • **Noise**: Long persistent noise from treatment plant and generator. A small portion from vehicle movements	Refer to management measures outlined for 8.1 Implementation of development plan. Further measures include: • Reusing treated producing water to suppress dust emissions for access road and sites. • Injection of produced water into the same or another suitable formation. • Treatment of produced water to meet onshore discharge or use. • Reuse of produced water in oil and gas operations such as for drilling, stimulation and workover operations.	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Atmosphere	• If containment is breached, contaminated groundwater aquifers may affect local water resources. Contaminated surface water may affect local water habitat, flora and fauna. • Increased air pollution into the surrounding areas from the water treatment plant. • The toxic nature of produced water can change surrounding flora diversity. • Noise from the treatment plant is	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate **Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low **Releases to air (local and global)**: Likelihood - rare, Consequence - slight, Risk: 2 low **Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise	**Groundwater**: Likelihood – Occasional, Consequence – moderate, Risk: 9 high **Surface water**: Likelihood - occasional, Consequence - moderate, Risk: 9 High **Releases to air (local and global)**: Likelihood - occasional, Consequence - slight, Risk: 3 low **Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low	Leak detection and repair programmes: Likely to be applied (90%) Treatment and analysis systems for PW and oil content: Likely to be applied (90%) Design and management of systems for cooling: Likely to be applied (90%) Treatment and analysis of discharged water: Likely to be applied (90%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
						low but persistent which can irritate local residents or fauna. • Contribution to global emissions (climate change, etc.)			
		11.5 Utility systems - Wastewater and sewage collection and treatment	• **Groundwater contamination**: long term contamination of surface spills and leakages • **Surface water** : Surface runoff contaminated by wastewater and sewage • **Releases to air**: emissions from treatment plant and generator • **Noise**: Long persistent noise from treatment plant and generator. A small portion from vehicle movements • **Traffic**: some increased movement of vehicles for disposal	Refer to management measures outlined for 8.1 Implementation of development plan.	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Local residence/ communities • Atmosphere	• If containment is breached, contaminated groundwater aquifers may affect local water resources. Contaminated surface water may affect local water habitat, flora and fauna. • Increased air pollution into the surrounding areas from the wastewater treatment plant. • Noise from the treatment plant is low but persistent which can irritate local residents or fauna. • Contribution to global emissions (climate change, etc.)	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate **Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low **Releases to air (local and global)**: Likelihood - rare, Consequence - slight, Risk: 2 low **Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise **Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Groundwater**: Likelihood – Occasional, Consequence – moderate, Risk: 9 high **Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local and global)**: Likelihood - occasional, Consequence - slight, Risk: 3 low **Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low **Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low	Leak detection and repair programmes: Likely to be applied (90%) Treatment and analysis systems for PW and oil content: Likely to be applied (90%) Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU Treatment and analysis of discharged water: Likely to be applied (90%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
		11.6 Waste Handling - Waste handling, storage, collection and transport	• **Groundwater contamination**: long term contamination of surface spills and leakages • **Surface water** : Accidental release • **Releases to air**: emissions from waste treatment e.g. incineration, TDUs, treatment plant, vehicle exhaust and generators. • **Noise**: Noise from treatment plant and generator. A small portion from vehicle movements • **Traffic**: Movement of vehicles for disposal	Refer to management measures outlined for 8.1 Implementation of development plan. Further measures include: • Use of chemicals with lower environmental impact (e.g. PLONOR) for drilling operations. • Re-use, recycling and minimisation of waste. • Appropriate and effective pre-treatment facilities (e.g. thermal desorption and detoxification).	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Local residence/ communities • Local traffic infrastructure • Atmosphere	• Contaminated surface water by waste can affect local water habitat, flora and fauna changing the environment of the area. • Increased air pollution into the surrounding areas from the waste treatment facilities. • The toxic nature of hazardous waste can destroy flora and fauna. Loss of biodiversity. • Noise from the treatment plant is low but persistent which can irritate local residents or fauna. • Contribution to global emissions (climate change, etc.)	**Groundwater**: Likelihood – Rare, Consequence – moderate, Risk: 6 moderate **Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low **Releases to air (local and global)**: Likelihood - occasional, Consequence - slight, Risk: 3 low **Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise. **Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Groundwater**: Likelihood – Occasional, Consequence – moderate, Risk: 9 high **Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local and global)**: Likelihood - likely, Consequence - slight, Risk: 4 low **Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low **Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low	Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%)
		11.7 Hydrocarbon offtakes - product export, onshore pipelines / road tankers within the	• **Surface water:** Leakage from pipeline within the site • **Releases to air**: vehicle emissions and pipe leaks • **Noise**: vehicle noise • **Traffic**: increase burden on local infrastructure, increase numbers of vehicles	Refer to management measures outlined for 8.1 Implementation of development plan.	• Local flora and fauna • Surface water bodies • Atmosphere	• Pipes on site may leak leading to air pollution from VOCs, changing surface water characteristics from oil pollution.	**Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low **Releases to air (local)**: Likelihood - rare, Consequence - slight, Risk: 2 low	**Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local)**: Likelihood - likely, Consequence - slight, Risk: 4 low	Emergency plans, including spill clean-up: Likely to be applied (90%)

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
		production process boundary.				• Traffic noise irritation local residents and affecting fauna. • Contribution to global emissions (climate change, etc.)	**Releases to air (global)**: Likelihood – Highly likely, Consequence - slight, Risk: 5 moderate	**Releases to air (global)**: Likelihood – Highly likely, Consequence - Minor, Risk: 10 high	
							Noise: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low	
							Traffic: Likelihood - likely, Consequence - Slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood - likely, Consequence - Slight, Risk: 4 low	
		11. 8 Enhanced recovery – water flooding – water injection to sweep field and boost production.	• **Releases to air:** Emissions from equipment used to filter, pressurise and inject water. • **Water resource depletion:** Significant quantities of water required. • **Land take:** Extra equipment and water storage • **Noise:** injection equipment • **Visual impact:** injection equipment • **Traffic:** increased production and produced water. Equipment must be brought to site.	Refer to management measures outlined for 8.1 Implementation of development plan. Additional measures include: ▪ BAT technology for low sulphur fuels in vehicles and pressurising equipment. ▪ Maintenance programs for all equipment ▪ Noise abatement measures ▪ Careful planning of water resource with comprehensive understanding of reservoir characteristics, production volumes, hydrogeology,	• Local flora fauna • Atmosphere • Local water source	• Water resource depletion can have adverse impacts on local flora and fauna. • Emissions of pollutants cause adverse effects to health • Noise affecting migrating birds • Contribution to global emissions (climate change, etc.)	**Releases to air (local air quality):** Likelihood – occasional, consequence, slight, risk: 4moderate	**Releases to air (local air quality):** Likelihood – occasional, consequence, minor, risk: 6 moderate	Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%) Maintenance programs for all equipment: Likely to be applied (90%) Environmental planning: Likely to be applied (90%)
							Releases to air (global): Likelihood – rare, consequence, minor, risk: 3 low No change as measures have only a small impact on total CO_2 emissions.	**Releases to air (global):** Likelihood – rare, consequence, minor, risk: 3 low	
							Water resource depletion: likelihood – rare, consequence – minor, risk: 4 low	**Water resource depletion:** likelihood – occasional, consequence – minor, risk: 6 moderate	
							Land take: likelihood – likely, consequence – minor, risk: 8 moderate	**Land take**: likelihood – highly likely,	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
				engineering design, and environmental considerations.				consequence – minor, risk: 9 high	
							Noise: likelihood – occasional, consequence – slight, risk: 4 low	**Noise:** likelihood – occasional, consequence – minor, risk: 6 moderate	
							Visual impact: likelihood – rare, consequence – slight, risk: 2 low No change as equipment for water injection does not significantly increase visual impact	**Visual impact:** likelihood – rare, consequence – slight, risk: 2 low	
							Traffic: likelihood – occasional, consequence – slight, risk: 4 low	**Traffic:** likelihood – highly likely, consequence – slight, risk: 5 moderate	
							Seismic: likelihood – rare, consequence – slight, risk: 2 low. No change as enhanced recovery / well stimulation always carries a small risk of induced seismicity.	**Seismic:** likelihood – rare, consequence – slight, risk: 2 low	
		11.9 Enhanced recovery (substance injection) – steam / miscible gas / polymer injection	• **Releases to air:** Emissions from equipment used to filter, pressurise and inject. • **Surface water contamination:** chemicals leakage or runoff from site storage / injection equipment. • **Ground water contamination:** injection chemicals penetrating ground water reserves after injection.	Refer to management measures outlined for 8.1 Implementation of development plan. Additional measures include: ▪ BAT technology for low sulphur fuels in vehicles and pressurising equipment.	• Local flora fauna • Atmosphere • Surface waters • Ground water reserves	• Emissions of pollutants cause adverse effects to health • Noise affecting migrating birds • Contribution to global emissions (climate change, etc.)	**Releases to air (local air quality):** Likelihood – occasional, consequence, slight, risk: 4moderate	**Releases to air (local air quality):** Likelihood – occasional, consequence, minor, risk: 6 moderate	Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%) Maintenance programs for all equipment: Likely to be applied (90%)
							Releases to air (global): Likelihood – rare, consequence, minor, risk: 3 low No change as measures have only a small impact on total CO_2 emissions.	**Releases to air (global):** Likelihood – rare, consequence, minor, risk: 3 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			• **Land take:** Extra equipment and chemical/water storage • **Noise:** injection equipment • **Visual impact:** injection equipment • **Traffic:** Equipment and materials must be brought to site. Waste must be removed	▪ Maintenance programs for all equipment ▪ Noise abatement measures ▪ Use of chemicals with lower environmental impact (e.g. PLONOR). ▪ Bunding, protected skids and totes for fluid storage.		• Contaminated surface water by waste can affect local water habitat, flora and fauna changing the environment of the area.	**Ground water contamination:** likelihood –rare, consequence – moderate, risk: 6 moderate	**Ground water contamination:** likelihood –occasional, consequence – moderate, risk: 9 high	Environmental planning: Likely to be applied (90%) Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU Bunding, protected skids, totes: Likely to be applied (90%)
							Surface water contamination: likelihood –rare, consequence – moderate, risk: 6 moderate	**Surface water contamination:** likelihood –occasional, consequence – moderate, risk: 9 high	
							Land take: likelihood – likely, consequence – minor, risk: 8 moderate	**Land take**: likelihood – highly likely, consequence – minor, risk: 9 high	
							Noise: likelihood – occasional, consequence – slight, risk: 4 low	**Noise:** likelihood – occasional, consequence – minor, risk: 6 moderate	
							Visual impact: likelihood – rare, consequence – slight, risk: 2 low No change as equipment for water injection does not significantly increase visual impact	**Visual impact:** likelihood – rare, consequence – slight, risk: 2 low	
							Traffic: likelihood – occasional, consequence – slight, risk: 4 low	**Traffic:** likelihood – occasional, consequence – slight, risk: 6 moderate	
							Water resource depletion: likelihood – rare, consequence – slight, risk: 2 low	**Water resource depletion:** likelihood – rare, consequence – minor, risk: 4 low	
							Seismic: likelihood – rare, consequence – slight, risk: 2 low. No	**Seismic:** likelihood – rare, consequence – slight, risk: 2 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							change as enhanced recovery / well stimulation always carries a small risk of induced seismicity.		
		11.10 Well stimulation (low volume hydraulic fracturing) – fracturing to release gas and/or oil.	• **Surface water contamination:** chemicals / proppant leakage or runoff from site storage / injection equipment. • **Ground water contamination:** fracturing chemicals / proppant penetrating ground water reserves • **Land take:** Extra equipment and chemical/water storage • **Noise:** injection equipment • **Visual impact:** injection equipment • **Traffic:** Equipment and materials must be brought to site. Flowback waste must be removed • **Releases to air:** Emissions from equipment used to filter, pressurise and inject. • **Water resource depletion:** Significant quantities of water required. • **Seismic:** high pressures applied to the formation	Refer to management measures outlined for 8.1 Implementation of development plan. Additional measures include: ▪ BAT technology for low sulphur fuels in vehicles and pressurising equipment. ▪ Maintenance programs for all equipment ▪ Noise abatement measures ▪ Use of chemicals with lower environmental impact (e.g. PLONOR). ▪ Bunding, protected skids and totes for fluid storage.	• Local flora fauna • Atmosphere • Surface waters • Ground water reserves • Local water resource	• Emissions of pollutants cause adverse effects to health • Noise affecting migrating birds • Contribution to global emissions (climate change, etc.) • Water resource depletion can have adverse impacts on local flora and fauna. • Seismicity can affect flora and fauna. • Contaminated surface water by waste can affect local water habitat, flora and fauna changing the environment of the area.	**Releases to air (local air quality):** Likelihood – occasional, consequence, slight, risk: 4moderate	**Releases to air (local air quality):** Likelihood – occasional, consequence, minor, risk: 6 moderate	Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%) Maintenance programs for all equipment: Likely to be applied (90%) Environmental planning: Likely to be applied (90%) Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU Bunding, protected skids, totes: Likely to be applied (90%)
							Releases to air (global): Likelihood – rare, consequence, minor, risk: 3 low No change as measures have only a small impact on total CO_2 emissions.	**Releases to air (global):** Likelihood – rare, consequence, minor, risk: 3 low	
							Ground water contamination: likelihood –rare, consequence – moderate, risk: 6 moderate	**Ground water contamination:** likelihood –occasional, consequence – moderate, risk: 9 high	
							Surface water contamination: likelihood –rare, consequence – minor, risk: 4 low	**Surface water contamination:** likelihood –occasional, consequence – minor, risk: 6 moderate	
							Land take: likelihood – likely, consequence – slight, risk: 6 moderate	**Land take**: likelihood – likely, consequence – minor, risk: 8 moderate	
							Noise: likelihood – occasional, consequence – slight, risk: 4 low	**Noise:** likelihood – occasional, consequence – minor, risk: 6 moderate	
							Visual impact: likelihood – rare, consequence – slight, risk: 2 low	**Visual impact:** likelihood – rare, consequence – slight, risk: 2 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
							No change as equipment for water injection does not significantly increase visual impact **Traffic:** likelihood – occasional, consequence – slight, risk: 4 low **Water resource depletion:** likelihood – rare, consequence – slight, risk: 2 low **Seismic:** likelihood – rare, consequence – slight, risk: 2 low. No change as enhanced recovery / well stimulation always carries a small risk of induced seismicity.	**Traffic:** likelihood – occasional, consequence – slight, risk: 6 moderate **Water resource depletion:** likelihood – rare, consequence – minor, risk: 4 low **Seismic:** likelihood – rare, consequence – slight, risk: 2 low	
Stage 4 Well decommissioning	12. Decommissioning and rehabilitation	**12.1 Project cessation, well closure and decommissioning**	**Desk based task** - no specific risk identified so not considered further	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-
	13. Decommissioning of equipment and reclamation	**13.1 Plugging of wells Removal of well pads Waste management**	• **Groundwater contamination**: spillage and leakage onsite. • **Surface water:** spillage and leakage onsite. • **Releases to air**: odour and fugitive emissions from chemical leaks and insufficient plugging. • **Land take and visual impact**: not all installations can be	• **General**: Development and implementation of a decommissioning plan (as outlined during exploration and development planning). • Good deconstruction practices, including design for well abandonment • Specific post closure risk assessment, well	• Local flora and fauna • Surface water bodies • Groundwater aquifers • Local residence/ communities • Atmosphere	• A short-term increase in traffic leading to more air pollution, dust emissions from dry roads and disturbance to local residents and flora and fauna. • Contribution to global emissions	**Groundwater**: Likelihood – rare, Consequence – moderate, Risk: 6 Moderate **Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low **Releases to air (local)**: Likelihood - Rare,	**Groundwater**: Likelihood – Occasional, Consequence – moderate, Risk: 9 high **Surface water**: Likelihood - occasional, Consequence - minor, Risk: 6 moderate **Releases to air (local)**: Likelihood -	Environmental planning: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%) Design and management of systems for cooling:

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
			removed to ensure plugged well is permanently stable. • **Biodiversity impacts**: Impact to soil from accidental spillages, vehicles, etc. • **Noise and traffic**: Increased construction noise and traffic from vehicles and workers to dismantle	plugging, inspection and monitoring requirements (e.g. for releases to air, water quality of nearby aquifers and freshwater, well integrity, periodicity of inspections (regular inspections by the operator and third party audits), wellhead monitoring every 90 days over a period which satisfies the regulating authority ? , etc.) • **Biodiversity**: Removal of invasive species grown on the site. • **Landtake**: Slope stabilisation. Re-vegetation to avoid and minimise erosion.		(climate change, etc.)	Consequence - minor, Risk: 4 low	Occasional, Consequence - minor, Risk: 6 moderate	Likely to be applied (90%) Controlled fall-pipe for rock dumping: Possible to be applied (40%) Measures for low sulphur content of fuels in exhaust engines: Possible to be applied (40%) Emergency plans, including spill clean-up: Likely to be applied (90%)
							Releases to air (global): Likelihood: Likely Consequence: Slight Risk: 4 (low)	**Releases to air (global):** Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	
							Land take: Likelihood - likely, Consequence - slight, Risk: 4 low	**Land take**: Likelihood - likely, Consequence - minor, Risk: 8 moderate	
							Visual impact: Likelihood - Likely, Consequence - slight, Risk: 4 low	**Visual impact**: Likelihood - Likely, Consequence - minor, Risk: 8 moderate	
							Biodiversity: Likelihood – Rare, Consequence - Minor, Risk: 4 low	**Biodiversity**: Likelihood – Occasional, Consequence - Minor, Risk: 6 moderate	
							Noise: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as measures may not be adopted and result in only a minor reduction in noise.	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low	
							Traffic: Likelihood - likely, Consequence - slight, Risk: 4 low. No change as large volumes of traffic are essential, therefore measures result in only a minor reduction.	**Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low	

Stages	Sub-stages	Processes/ technologies	Environmental Aspects	Expected management measures	Receptor	Impacts	Risk Characterisation (with expected management measures in place)	Risk Characterisation (without expected management measures in place)	Level of uptake for measures detailed[1]
	14. Rehabilitation	**14.1 Site restoration**	• **Noise and Traffic**: Vehicles and access road used to transport materials and equipment needed for site restoration.	Refer to management measures outlined for 13.1 Decommissioning of equipment and reclamation. Further measures include: • Implementation of site restoration plan. • Environmental monitoring (see 2.4.1 – licensing, for monitoring details) • Restoration of indigenous plant species • Restoration of drainage patterns.	• Local flora and fauna • Local traffic infrastructure	• Land is permanently changed to local infrastructure usage which changes level of baseline noise already in the area.	**Noise**: Likelihood - occasional, Consequence - Slight, Risk: 3 low **Traffic**: Likelihood - Occasional, Consequence - Slight, Risk: 3 low **Releases to air (local)**: Likelihood - Rare, Consequence - minor, Risk: 4 low **Releases to air (global):** Likelihood: Likely Consequence: Slight Risk: 4 (low)	**Noise**: Likelihood - likely, Consequence - slight, Risk: 4 low **Traffic**: Likelihood - likely, Consequence - slight, Risk: 4 low **Releases to air (local)**: Likelihood - Occasional, Consequence - minor, Risk: 6 moderate **Releases to air (global):** Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	-
Stage 5 Project post closure and abandonment	15. Post closure and abandonment	**15.1 Long-term well integrity and monitoring**	• **Groundwater contamination**: sub-surface leaks of hydrocarbon fluids can occur, resulting in the penetration of ground waters. • **Surface water:** Liquid hydrocarbons may leak from the mouth of the well bore. • **Releases to air:** Methane and other hydrocarbon gases may escape to the atmosphere.	• Regular pressure monitoring to determine well integrity as stipulated under the ES and EIA which is subjected to approval by the regulating authority. • Methane monitoring in the vicinity of the capped well.	• Atmosphere • Local flora and fauna	• Potential long-term pollution of waters that acts as both a habitat and resource to many species. • Long-term significant contributions to climate change	**Groundwater**: Likelihood – extremely rare, Consequence – minor, Risk: 2 low **Surface water**: Likelihood - rare, Consequence - minor, Risk: 4 low **Releases to air (global):** Likelihood: Rare Consequence: Minor Risk: 4 (low)	**Groundwater**: Likelihood – extremely rare, Consequence – moderate, Risk: 4 low **Surface water**: Likelihood – rare, Consequence - moderate, Risk: 6 moderate **Releases to air (global):** Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	On-going monitoring[5] of site by operators and as required with independent reviews by competent authorities post closure): Possible to be applied (40%)[6]

[5] Subject to the decision of competent authorities (for example in the UK: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297024/LIT_7983_3b53c2.pdf (page 29)).
[6] Based on the findings in Davies et al (2014) that to the best of their knowledge, post-closure monitoring is not carried out at all the UK, this may be an overestimate. However, there are several industry guidance documents which make reference to post-closure monitoring including OGP (1997), IGEM (2013) and IFC (2007). Additionally, the scope of the findings in the Davies et al (2014) study are limited relevant to this report, because they refer to only one jurisdiction within the EU. On this basis, the judgement that the measure is 'possible be applied (40%)' has been maintained.

Appendix B
Offshore processes, technologies, risks and management - process, techniques, risk and management matrix

The table below has been developed in order to capture key information for offshore 'conventional' oil and gas extraction. It covers what the project team identified as the main processes and technologies applied (at a high level), potential environmental risks associated with these processes and a review of potential management measures. Following this, a conclusion is drawn on the level of risk with and without the specified management measures in place. This conclusion is formulated using judgement, and is hence open to interpretation depending on the particular types of field and oil and gas activities.

Processes/technologies: The main processes associated with oil and gas facilities, focusing on those with potential for environmental impacts (but not aiming for a comprehensive list of all processes).

Environmental aspect: An element of a process or technology that interacts with the environment. Environmental aspects can cause either positive or negative environmental impacts.

Expected management measures: Measures typically in place prevent, detect, control, or mitigate risks associated with the environmental hazard, or remediate their impacts.

Receptor: Living organisms, the habitats which support such organisms, or natural resources which are affected by environmental impacts.

Impacts: The change to the environment caused, directly or indirectly, by one or more environmental aspects.

Risk level: Determined by assessing the consequences (to what extent the receptor is being impacted) and likelihood (how likely it is that the identified impacts will occur, assuming that typical management measures are in place). Scoring as per the agreed matrix. A further column identifies the risk level without the specified risk management measures in place. This is not the same as an 'unmitigated' risk, as other design, etc. factors serve to help mitigate the risks.

Management measures: For the management measures identified, this considers the extent to which it is applied in contemporary practices.

Categories for environmental risks/impacts:

- Seabed disturbance
- Discharges to sea
- Releases to air
- Physical presence
- Marine biodiversity impacts [CC note: This may be a consequence of other impact types e.g. seabed disturbance, noise, lighting]
- Underwater noise
- Visual impact (for near shore operations)

Note: The 'environmental aspect' column includes both planned and accidental events for each of the above.

The table draws on information from a variety of Environmental Statements (ESs) prepared as part of Environmental Impact Assessments (EIAs) conducted on the offshore industry largely based from the North Sea . In addition, we have utilised internal expertise for the interpretation and assessment of environmental risks associated with exploration and production.

Potential uptake rates for measures have been estimated as either 'Likely to be applied' or 'possible to be applied' using expert judgement. These qualitative indicators have also been translated to an approximate percentage of uptake (90% and 40% respectively), as per the approach used for shale gas in AMEC (2014). In the 2014 report the costs of implementing risk management measures fed into a quantitative impact assessment, therefore to avoid an overestimation of impacts for those measures which were not systematically used by all operators, costs were adjusted downward to reflect a (purely hypothetical) average level of uptake. Specifically, 10% of compliance costs was assumed for the measures that were considered to be *likely to be applied* (i.e. 90% uptake level) and 60% of costs for the measures considered to be *possible to be applied* (i.e. 40% uptake level). The percentage uptake figures, suggested by the Commission, were therefore only illustrative and were not intended to be predictors of actual uptake of any individual measure by operators.

For offshore activities, it is recognised that for some aspects, environmental risks may be greater when the rig is located in challenging conditions such as deeper waters, high winds, low temperatures and rough seas. Aspects for which risks after measures have been applied are likely to vary based on these conditions are noted in the risk assessment, with an explanation included.

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
1. Site identification and preparation	1.1 Surveying	1.1.1 Gravimetric surveys, seismic surveys	Underwater noise: Seismic activity	Environmental impact assessment (EIA)[2] to review potential impact species, breeding and migratory seasons. Seismic programme scheduled outside breeding/migration times Whale watch on seismic vessel Passive aquatic monitoring (PAM) below water to detect whale sounds close to site of operation (Ffyne, Mariner & Edradour, Peterhead). This should follow the guidelines (2010) set down by the Joint Nature Conservation Committee (JNCC) Country specific environmental applications (e.g. PON 15 in the UK) 'Soft starts' for seismic equipment	Marine fauna including mammals (e.g. Cetaceans, porpoises, seals), Commercial and non-commercial fish populations, seals, turtles, etc. Includes protected marine species.	Behavioural responses in marine fauna.	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: Highly Likely Consequence: Slight Risk: 5 (moderate)	Whale watch: Likely to be applied (90%) PAM: Likely to be applied (90%) Soft start of seismic equipment: Likely to be applied (90%)
						Damage/injury to marine fauna , e.g. physiological damage	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	

[1] For measures that are considered to be '*likely to be applied*', an approximate uptake level of 90% is assumed. For measures that are considered to be '*possible to be applied*' an approximate uptake level of 40% is assumed.

[2] An EIA is mandatory if the development is expected to produce more than 500t oil or 500,000m3 gas per day (EIA Directive 2011/92/EU amended by Directive 2014/52/EU). For projects below this threshold, surface industrial installations for petroleum and gas extraction as well as deep drillings, the competent authority screens these projects to determine whether they are likely to have a significant adverse effect on the environment. In the event that the competent authority does not deem it necessary to conduct an EIA in order to grant the permit, then associated risk management measures may not be applied. However, this is only for projects where environmental risk has been deemed to be low enough for these measures not be required.

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Releases to air: Emissions from surveying vessels (CO, CO2, NOx and SOx, etc.) Pollution levels considered consistent with typical shipping operations worldwide Risk presented here is on the basis of per campaign. Impacts will depend on asset location/nature of operations.	BAT measures for marine shipping pollution and EIAPP certification for vessels (under Marpol) EIA[3] includes impact assessment for air pollution and greenhouse gas emissions. This may include carbon footprints and measures to reduce fuel consumption where possible (e.g. Ffyne, Kew, Edradour & Peterhead). Sulphur Emission control areas (SECAs) adhered to per Marpol / EU Directive 2005/33/EC.	Local flora and fauna	Local air quality - pollution	Likelihood: Occasional Consequence: Slight Risk: 3 (low). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	BAT technologies for low sulphur content of fuels in shipping: Possible to be applied (40%)
					Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	
2. Well design and construction	2.1 Well design	2.1.1 Desk based task - no specific risks identified	–	–	–	–	–	-	

[3] See footnote 2.

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
and well completion	2.2. Transport of drilling rig Well drilling (also covers exploratory wells)	2.2.1 Transport of drilling rig, supply vessels Number of vessels depends on project and frequency of vessel movement.	Releases to air: Emissions from drill rig transport and supply vessels (CO, CO2, NOx and SOx, etc.) Aspect is not specific to offshore oil and gas, and may relate to any shipping vessels operating worldwide	EIAPP certification for vessels (under Marpol – applies internationally) and BAT technologies for low sulphur fuel, exhaust gas cleaning, etc.	Local flora and fauna	Local air quality - pollution	Likelihood: Occasional Consequence: Slight Risk: 3 (low). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	BAT technologies for low sulphur content of fuels in shipping: Possible to be applied (40%)
					Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: High Likely Consequence: Slight Risk: 5 (moderate). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	Likelihood: High Likely Consequence: Slight Risk: 5 (moderate)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Loss of containment of diesel from drill rig transport or supply vessels Accidental event which may be caused by collision, equipment failure, human error, etc. Diesel inventories may be up to tier I / tier II spills (maximum c200-400m3). Lighter hydrocarbons such as diesel are considered to disperse more rapidly in the marine environment. Aspect is not specific to offshore oil and gas, and may relate to any diesel powered shipping vessels operating worldwide. In rough seas and high winds, the risk of a containment failure may increase as there are narrower margins for error when loading and unloading from the rig.	Design of double skinned vessel hulls/fuel tanks that position cargo away from potential impact locations. Spill response and clean-up procedures in place to assist in spill remediation in a timely manner. Consent to locate permits submitted to regulator prior to offshore operations starting (e.g. Ffyne & Ythan) Potential for exclusion zones around offshore facilities during operations to prevent collision. This can be enforced using support vessels (e.g. Ffyne, Mariner, Ythan, Edradour) Maintenance of vessels and equipment to ensure optimal performance and reduce likelihood of failure. Training and competence verification of marine operators.	Marine flora and fauna	Toxicity and habitat damage from local hydrocarbon pollution	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	Likelihood: Occasional Consequence: Moderate Risk: 9 (high)	Double skinned vessel hulls/fuels tanks positioned to reduce potential impact: Possible to be applied (40%) Exclusion zones around the rig and platform: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Loss of containment of toxic chemicals from drill rig transport or supply vessels (e.g. OBM, drilling chemicals) In rough seas and high winds, the risk of a containment failure may increase as there are narrower margins for error when loading and unloading from the rig.	Typically only small quantities stored Chemicals stored inside protected skids/tote tanks Emergency plans and training for all personnel on board the platform in the event of a leak/loss of containment identified (Ffyne, Mariner & Ythan) Hazardous chemicals stored in designated areas with bunding and drain systems to contain leaks (Ffyne, Mariner & Ythan)	Marine flora and fauna	Toxicity and habitat damage from local chemical pollution	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Use of bunding/protected skids/tote tanks for chemical storage: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		2.2.2 Positioning of apparatus on seabed for exploratory drilling	Physical presence: Seabed disturbance drilling vessel positioning: - Floating facilities (e.g. MODUs and drill ships): Anchoring spread and anchor chain scouring can occur - Fixed facilities (e.g. jackups): Leg positioning, spud cans In deeper waters, the seabed disturbance caused by positioning apparatus on the seabed may be increased, as the placement is less accurate.	Plan for anchor patterns if floating facilities used (Edradour), and plan for rig seabed placement if fixed facilities used. (Highly likely) Use of directional positioning (DP) vessels Survey and planning for drilling vessel mobilisation (Ffyne, Mariner, Ythan & Edradour) Highly likely) EIA[4] to determine site-specific risks and impacts. (Highly likely) Construction planning to select options with minimal impact, e.g. use of 'trenching' or back-filling to minimise the need for rock dumping/ concrete mattresses (Kew) Potentially adopted) ROV assessment of pipelines post laying and further amendment of sea-bed to reduce 'mounds' if necessary (Mariner) Potentially adopted)	Marine flora and fauna	Damage to marine life habitat on sea floor – local impact depending on nature of seabed environment	Likelihood: Highly likely Consequence: Slight Risk: 5 (Moderate)	Likelihood: Highly likely Consequence: Minor Risk: 10 (High)	Use of DP vessels: Possible to be applied (40%)

[4] See footnote 2.

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Underwater noise: piling for seabed apparatus	Refer to 1.1.1	Marine fauna including mammals (e.g. cetaceans, porpoises, seals), commercial and non-commercial fish populations, seals, turtles, etc. Includes protected marine species.	Behavioural responses in marine fauna.	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: Highly Likely Consequence: Slight Risk: 5 (moderate)	Refer to 1.1.1
			Drilling vessel introducing Invasive/ foreign species to area	Quarantine measures for incoming vessels Ballast water change out procedures. Use of sea-water for ballast taken only from the area of operation to avoid translocation of marine species (Ythan)	Marine flora and fauna	Habitat modification, impact on local biodiversity	Likelihood: Rare Consequence: Moderate Risk: 6 Moderate	Likelihood: Likely Consequence: Moderate Risk: 12 High	Quarantine measures for vessels to avoid invasion of marine species: Possible to be applied (40%)
		2.2.3 Drilling using water based muds (WBM)/oil based muds (OBM)	Physical presence: Accidental seabed disturbance (e.g. debris, dropped objects)	Lifting procedures Maintenance of cranes and other lifting equipment EIA[5] to assess potential damage and timespan for return to nature post activity (Ffyne, Ythan, Edradour, Kew, Mariner & Peterhead) and to ensure risk is managed on a site-specific basis.	Benthic flora and fauna Sediments/benthic habitat	Impact on marine biodiversity Habitat modification Loss of directly affected benthic flora and fauna	Likelihood: Occasional Consequence: Slight Risk: 3 low. No change as even with measures in place, a degree of physical disturbance is unavoidable.	Likelihood: Occasional Consequence: Slight Risk: 3 low	Lifting procedures: Likely to be applied (90%) Maintenance programs for all equipment: Likely to be applied (90%)

[5] See footnote 2.

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Underwater noise: Well drilling Impact is not as significant as seismic or piling because sound is short term, continuous and relatively low power (Semi-submersibles produce 154dBs, compared to the harm threshold of 220dB quoted in Richardson (1995) and Genesis report 2011).	Maintenance programs for all equipment EIA[6] to assess the likely issues from noise and to ensure risk is managed on a site-specific basis. Noise propagation models used to assess intensity during different activities. (Edradour and Peterhead ES)	Marine fauna	Behavioural responses in marine fauna.	Likelihood: Rare Consequence: Slight Risk: 2 Low	Likelihood: Occasional Consequence: Slight Risk: 3 Low	Maintenance programs for all equipment: Likely to be applied (90%)
			Releases to air: Emissions from drilling rig (CO, CO2, NOx and SOx, etc.)	EIAPP certification for vessels (under Marpol) Low sulphur fuel, exhaust gas cleaning, etc. Compliance with MARPOL emissions standards and use of BAT for equipment (Ffyne) Air quality regulations depending on platform location.	Local flora and fauna	Local air quality - pollution	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Likely Consequence: Minor Risk: 8 (moderate)	Refer to 2.2.1
					Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: High Likely Consequence: Minor Risk: 10 (High)	
			Discharges to sea: Residual chemical additives/hydrocarbons to sea (planned release) Relates to all activities for the drilling rig phase of the operation. The assessment of hazards and risks presented in this part of the table assumes all relevant management	Chemical selection procedure prioritising: - Lowest toxicity - Lowest persistence - Lowest bioaccumulation potential (e.g. selection according to CHARM protocols, PLONOR for inorganics)	Marine flora and fauna Water Sediments/benthic habitat	Marine biodiversity/ habitat loss or modification (e.g. Loss of directly affected benthic flora and fauna, fish taint)	Likelihood: Occasional Consequence: Slight (impact on marine flora and fauna) Risk: 3 (low)	Likelihood: Occasional Consequence: Minor (impact on marine flora and fauna) Risk: 6 (moderate)	Use of low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices

[6] See footnote 2.

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			measures have been adopted, which reduces the risk rating. Potential causes: - Mud additives in cuttings - Drainage water containing quantities of hydrocarbons - Sewage water released - Ballast discharge released containing contaminants	(Kew, Peterhead, Mariner & Ythan) Sampling and analysis of materials for threshold concentrations. Only below threshold can be released (Ffyne, Mariner, Ythan & Edradour) Drainage system Oil and water (OIW) separation system Regulatory requirements encouraging use of less toxic chemicals (e.g. OSPAR Convention use of PLONOR chemicals, OCR offshore chemical regulations guidelines from DECC UK) Country specific environmental applications (e.g. PON 15 in the UK) Dispersion modelling (e.g. DREAM/CHARM chemical risk assessment model in the UK) to ensure appropriate dilution.		Deterioration in water quality	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	may differ across EU
						Sediment fouling	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Likelihood: Occasional Consequence: Moderate Risk: 9 (High)	
			Discharges to sea: Accidental hydrocarbon spill – Tier III (requiring assistance from third party resources) Potential causes:	Primary well control (mud) Use of blow-out preventer Valve assembly systems to manage flow of	Marine flora and fauna Intertidal/coastal flora and fauna Water quality	Marine biodiversity/ habitat loss	Likelihood: Rare Consequence: Catastrophic Risk: 10 (High)	Likelihood: Likely Consequence: Catastrophic Risk: 20 (Very High)	Blow-out preventer: Likely to be applied (90%) Valve systems including SSIVs,

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			- Well blowout - FPSO hull tank failure - Offtake vessel hull tank failure - Export pipeline rupture The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error	material and prevent loss to sea. This can include X-mas tree assemblies, subsea isolation valves (SSIVs) and Choke and kill systems. (Mariner, Kew, & Edradour) Well pressure monitoring (well management) Emergency plans and training including spill clean-up procedures and if necessary specialist spill response operators. Spill clean-up resources (marine and coastal)	Sediments/benthic habitat	Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Catastrophic Risk: 10 (High)	Likelihood: Likely Consequence: Catastrophic Risk: 20 (Very High)	choke and kill systems, and X-mas tree: Likely to be applied (90%) Well pressure monitoring: Likely to be applied (90%) Emergency plans, including spill clean-up: Likely to be applied (90%)
						Deterioration in water quality	Likelihood: Rare Consequence: Catastrophic Risk: 10 (High)	Likelihood: Likely Consequence: Catastrophic Risk: 20 (Very High)	
						Sediment fouling	Likelihood: Rare Consequence: Moderate Risk: 6 (Moderate)	Likelihood: Occasional Consequence: Major Risk: 12 (High)	
			Discharges to sea: Accidental hydrocarbon spill - Tier II (requiring assistance from other Operator resources) Typical causes: - In-field riser/flowline rupture - Topsides vessel / heat exchanger rupture - Fuel tank loss of containment - Topsides drainage system failure The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is	Subsea isolation valves Process system monitoring Spill clean-up procedures Spill clean-up resources (marine and coastal) as well as potentially third party specialist spill response contractors.	Marine flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Rare Consequence: Major Risk: 8 (Moderate)	Likelihood: Likely Consequence: Major Risk: 16 (Very High)	Valve systems including SSIVs, choke and kill systems, and X-mas tree: Likely to be applied (90%) Emergency plans, including spill clean-up: Likely to be applied (90%)
						Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Major Risk: 8 (moderate)	Likelihood: Likely Consequence: Catastrophic Risk: 20 (Very High)	
						Deterioration in water quality	Likelihood: Rare Consequence: Major Risk: 8 (Moderate)	Likelihood: Likely Consequence: Major Risk: 16 (Very High)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			because there is greater stress put on containment equipment and lower margins for operator error			Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Occasional Consequence: Moderate Risk: 9 (Moderate)	
			Discharges to sea: Accidental hydrocarbon spill – Tier I (can be dealt with by local Operator resources) Typical causes: - Bunker hose failure - Dropped tote tank - Small-hole riser leak - Helideck fuel spills The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error	Spill clean-up procedures Spill clean-up resources (marine and coastal) Hazardous chemicals stored in designated areas with bunding and drain systems to contain leaks. Quick-release valves for remotely detaching during decanting/hose operations. Spill response plans and training for personnel to respond quickly during an incident. Visual checks of equipment and general maintenance to look for any hose line issues in advance.	Marine flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Likelihood: Likely Consequence: Moderate Risk: 12 (High)	Quick release valve systems: Possible to be applied (40%)
						Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Minor Risk: 4 (low). No change as measures cannot reduce the risk any further.	Likelihood: Rare Consequence: Minor Risk: 4 (low)	
						Deterioration in water quality	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	
						Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		2.2.4 Handling of OBM cuttings	Discharges to sea: Discharges of drilling cuttings potentially contaminated with residual OBM May occur during drilling and subsequent clean up More concentrated cuttings have a more pronounced impact In rough seas and high winds, the risks of accidental discharges to sea may increase as there is greater stress put on containment equipment and lower margins for operator error during drilling, cementing and casing.	Refer to 2.2.3: Discharge to sea of cuttings potentially contaminated with residual WBM additives OBM separation, treatment and recycling (e.g. separation to ensure oil on dry cuttings is below a threshold, e.g. organic phase fluids in any discharged cuttings must be <1% w/w in OSPAR region, leading to de-facto elimination of discharge) Use of thermal cuttings cleaning (TCC) Disposal/treatment of contaminated cuttings onshore (required in HELCOM region)	–	–	–	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		2.2.5 Cementing and casing	Discharges to sea: Accidental release to sea of cement and associated chemical additives. Cement is mixed as a slurry on topsides and pumped into the well under pressure. Potential for small quantities to escape and be lost to sea. In rough seas and high winds, the risks of accidental discharges to sea may increase as there is greater stress put on containment equipment and lower margins for operator error during drilling, cementing and casing.	Refer to 2.2.3: Discharge to sea of cuttings potentially contaminated with residual WBM additives Well design Well construction procedures Cement use is minimised and restricted to mixing at the point of use only (Ffyne, Mariner, Kew, & Ythan)	–	–	–	-	-
			Underwater noise: Well cementing process Not expected to exceed noise from well drilling.	Refer to 2.2.3: Underwater noise Similar to other noise related risk elements, noise modelling can be used to assess the likely intensity and risk from given operations.	–	–	–	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
	2.3 Well Completion	2.3.1 Well-bore clean up	Discharges to sea: Liquid hydrocarbon drop-out to ocean surface resulting from incomplete combustion during flaring	Refer to 2.2.3: Residual chemical additives/ hydrocarbons to sea (planned release) Drilling vessel process system design Flare tip design Flare system design (including KO drum) Sea-watch to assess whether birds are in the area where drop-out might occur. Scaring birds off/waiting until they've gone before flaring (Peterhead)	–	–	–	-	-
			Discharges to sea: Discharge of hydrocarbon-contaminated waste water to sea from well clean-up. In rough seas and high winds, the risks of accidental discharges to sea may increase as there is greater stress put on containment equipment and lower margins for operator error during drilling, cementing and casing.	Refer to 2.2.3: Residual chemical additives/hydrocarbons to sea (planned release) Drains systems design Discharge testing and monitoring	–	–	–	-	
			Releases to air: Flaring emissions (NOx, SOx, GHG, smoke) Requirement depends on the Gas: Oil (GOR) ratio of	Flare tip design, BAT equipment and maintenance to ensure emissions are kept to minimum.	Local fauna and flora	Local air quality - pollution	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: Highly Likely Consequence: Minor Risk: 10 (High)	Flare tip design and metering: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			the field. If low, quantities of gas will nevertheless be present which need to be managed. Note that flaring during production is likely to be more significant and longer running than during the drilling phase.	According to the IPIECA (2015) green completions are not viable for offshore activities Planned and controlled flaring duration, and metered gas flaring (Ffyne) Well design (minimising requirement for extended clean-up flaring)	Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Likely Consequence: Slight Risk: 4 (Low)	Likelihood: High Likely Consequence: Minor Risk: 10 (High)	
		2.3.2 Introduction of completion fluids	Discharges to sea: Accidental discharge to sea of completion fluids (e.g. corrosion inhibitor, biocide, oxygen scavenger) resulting from loss of containment Accidental event which may be caused by equipment failure, human error, etc. The type of chemicals used in completion fluids include salts: such as potassium hydroxide, sodium hydroxide. They also include drilling muds	Refer to 2.2.3 : Residual chemical additives to sea (planned release) Inventory of chemicals on drilling vessels likely to be relatively small Completion fluid cycled through the well as a closed loop system. Emergency shutdown systems, SSIVs, X-tree valve assemblies	Marine flora and fauna Water Sediments/benthic habitat	Marine biodiversity/ habitat loss or modification (e.g. Loss of directly affected benthic flora and fauna, fish taint)	Likelihood: Occasional Consequence: Slight (impact on marine flora and fauna) Risk: 3 (low)	Likelihood: Occasional Consequence: Minor (impact on marine flora and fauna) Risk: 6 (moderate)	Low hazard/risk chemicals e.g. PLONOR under OSPAR: Likely to be applied (90%) Note likely to be applied in OSPAR region, but practices may differ across EU
						Deterioration in water quality	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			and trace quantities of oil/hydrocarbon fraction. In deeper waters there may be a greater chance of accidental discharges to sea during well completion, as a much greater length of the well bore is exposed to the ocean.			Sediment fouling	Likelihood: Occasional Consequence: Slight Risk: 3 (Low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	
3. Production	3.1 Platform installation – floating, fixed	3.1.1 EPC - Facility design and construction	Onshore design and construction – outside of scope for current study	-	-	-	-	-	-
		3.1.2 Transportation of platform to field	Releases to air: Emissions from platform transportation	Refer to 1.1.1 and 2.2.1: Releases to air, emissions from marine transport (CO, CO2, NOx and SOx, etc.)	–	–	–	-	-
		3.1.3 Piling for jacket foundations and/or mooring line anchors	Physical presence: Drilling vessel lighting	Shielding of light, adjust wavelength of light to that which is less receptive to birds. Selective use rather than on constantly. Flashing light cycle. Risk assessment to gauge the potential loss to bird populations. This would be expected to be more of an issue in autumn months (Peterhead ES)	Bird life 75% of birds killed are thrushes (OSPAR, 2012) (Commission Research into possible effects of residual platform lighting on specific bird populations)	Birds navigation distorted, resulting in fatalities on vessels	Likelihood: High Likely Consequence: Slight Risk: 5 (Moderate)	Likelihood: High Likely Consequence: Minor Risk: 10 (High)	Light management, including shielding, adjusted wave length, flashing light cycle: Possible to be applied (40%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Underwater noise: Piling Depends on the type of platform, e.g. Jack-up rigs have footings on the sea-bed and winching to bring platform into place, semi-submersibles require tethering/anchoring/use of DP to maintain position. Piling noise considered not to exceed that of seismic in terms of noise impacts.	Refer to 1.1.1: Underwater noise: Seismic activity 'Soft start' for piling equipment. In the first 20 minutes of drilling for piling, activity is reduced to ward off marine species before more intense rounds of drilling are used (Mariner)	–	–	–	-	-
			Releases to air: Emissions from installation vessels (NOx, SOx, GHG)	Refer to 1.1.1 and 2.2.1: Releases to air, Emissions from transport (CO, CO2, NOx and SOx, etc.)	–	–	–	-	-
			Discharges to sea: Unplanned loss of hydraulic fluid from piling equipment In deep waters and rough seas piling operations may be more inaccurate and margins for error lower, resulting in the potential for higher seabed disturbance and a greater risk of accidental fluid discharge.	Refer to 2.2.3: Residual chemical additives to sea (planned release)	–	–	–	-	-
			Seabed disturbance: Placing of equipment on the seabed and piling for jackets	Refer to 2.2.3: Seabed disturbance from piling activities	-	-	-	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		3.1.4 Rock dumping	Seabed disturbance: rock dumping Rock dumping is used to help fix platforms in place as an alternative to micro-piling, e.g. to prevent platform leg movement. Potential seabed disturbance depends on both rock dumping and potential for later removal of rock when field is decommissioned. In deeper waters and rougher seas, rock dumping may be more inaccurate, resulting in a greater seabed disturbance.	Optimisation of rock-dump requirements Use of controlled fall-pipe vessels Selection of rock size to minimise the impact on seabed. Possibility of additional trenching to reduce the need for rock dumping.	Sediments/benthic habitat	Sediment fouling/ smothering of benthic flora and fauna	Likelihood: Occasional Consequence: Moderate Risk: 9 (High). No change as even with measures in place, these practices are inherently highly disturbing to the seabed.	Likelihood: Occasional Consequence: Moderate Risk: 9 (High)	Use of controlled fall-pipe vessels for rock dumping: Possible to be applied (40%)
		3.1.5 Pre-commissioning (hydrostatic testing / leak testing and water injection)	Discharges to sea: Accidental discharge to sea of hydrotest chemicals In rough seas and high winds, the risk of test fluids loss may increase as equipment is under stress and there are lower margins for operator error.	Refer to 2.2.3: Residual chemical additives to sea (planned release)	–	–	–	-	-
		3.1.6 Installation of sea-bed production infrastructure Includes ESPs, hydraulically-powered pumps,	Underwater noise: installation of subsea infrastructure Includes initial installation and subsequent maintenance/replacement	Design of subsea infrastructure and planning of construction Noise modelling propagation models to assess impact.	Marine fauna	Behavioural responses in marine fauna.	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: Highly Likely Consequence: Slight Risk: 5 (Moderate)	Refer to 1.1.1

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		FLETS, PLETS, ESDVs, pigging equipment, manifolds, X-trees, etc. Also includes in-field flowlines, injection lines and umbilicals] Excluding piling	Seabed disturbance: Installation of subsea equipment Potential sea-bed disturbance from laying pipes, concrete mattresses, etc. Subsea networks can be complex with multiple flowlines and equipment. In rough seas and deeper waters establishing equipment on the seabed may be more inaccurate, therefore this may potential result in increased seabed disturbance.	Design of subsea infrastructure and planning of construction	Sediments/benthic habitat	Sediment fouling/ smothering of benthic flora and fauna	Likelihood: Likely Consequence: Moderate Risk: 12 (High). No change as even with measures in place, these practices are inherently highly disturbing to the seabed.	Likelihood: Likely Consequence: Moderate Risk: 12 (High)	-
	3.2 Platform operations	3.2.1 Chemical injection	Discharges to sea: Accidental release to sea of production chemicals The range and type of chemicals used in this phase are more significant than during well completion. Chemicals used in injection may include, e.g. methanol, scale inhibitor, corrosion inhibitor, demulsifier, asphaltene inhibitor) In rough seas and deeper waters the risk of accidental discharges to sea may increase as equipment is under greater pressure and there	Hazardous chemicals stored in designated areas with bunding and drain systems to contain leaks Chemical selection (assuming that PW discharge to sea is a planned option) Closed drain system on platform Valve assemblies to manage the flow of materials, such as X-mas tree assembly, SSIVs, coke and kill lines.	Marine flora and fauna Coastal flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Occasional Consequence: Slight Risk: 3 (Low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Refer to transport of drilling rig in 2.2.1
						Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Minor Risk: 4 (Low)	Likelihood: Rare Consequence: Moderate Risk: 6 (Moderate	Refer to transport of drilling rig in 2.2.1
						Deterioration in water quality	Likelihood: Occasional Consequence: Slight Risk: 3 (Low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			are lower margins for operator error.			Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Slight Risk: 2 (Low)	Likelihood: Rare Consequence: Minor Risk: 4 (Low)	
		3.2.2 Subsea production system Includes ESPs, hydraulically-powered pumps, FLETS, PLETS, ESDVs, pigging equipment, manifolds, X-trees, etc. Also includes in-field flowlines, injection lines and umbilicals	Discharges to sea: Discharge of hydraulic fluids (containing MEG and other chemicals) to sea, e.g. due to valve actuation For all accidental discharges to sea from subsea production systems, the risks may be greater in deeper and rougher waters, as there is greater pressure on the equipment.	Refer to 2.2.3 : Residual chemical additives to sea (planned release)	–	–	–	-	-
			Underwater noise: operation of subsea infrastructure	Design of subsea infrastructure and planning of construction	Marine fauna	Behavioural responses in marine fauna.	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Planning and design of subsea infrastructure: Likely to be applied (90%)
			Physical presence: Long term habitat loss from presence on Seabed	Design of subsea infrastructure and planning of construction	Sediments/benthic habitat	Sediment fouling/ smothering of benthic flora and fauna	Likelihood: Highly Likely Consequence: Minor Risk: 10 (High). No change as even with measures in place, these practices are inherently highly disturbing to the seabed.	Likelihood: Highly Likely Consequence: Minor Risk: 10 (High)	

<table>
<tr><th>Stage</th><th>Sub-stage</th><th>Processes/technologies</th><th>Environmental Aspect</th><th>Expected management measures</th><th>Receptor</th><th>Impacts</th><th>Risk level (with expected management measures in place)</th><th>Risk level (without expected management measures in place)</th><th>Level of uptake for measures detailed[1]</th></tr>
<tr><td rowspan="6"></td><td rowspan="6"></td><td rowspan="6">3.2.3 Oil production, processing and handling
The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error during production.</td><td rowspan="4">Discharges to sea: Accidental hydrocarbon spill – Tier III (requiring assistance from third party resources)
The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error during production.</td><td rowspan="4">Primary well control (mud)
Use of blow-out preventer
Valve assembly systems to manage flow of material and prevent loss to sea. This can include X-mas tree assemblies, subsea isolation valves (SSIVs) and Choke and kill systems. (Mariner, Kew, & Edradour)
Well pressure monitoring (well management)
Emergency plans and training including spill clean-up procedures and if necessary specialist spill response operators.
Spill clean-up resources (marine and coastal)</td><td>Marine flora and fauna
Intertidal/coastal flora and fauna
Water quality
Sediments/benthic habitat</td><td>Marine biodiversity/ habitat loss</td><td>Likelihood: Rare
Consequence: Major
Risk: 8 (Moderate)</td><td>Likelihood: Likely
Consequence: Catastrophic
Risk: 20 (Very High)</td><td rowspan="4">Blow-out preventer: Likely to be applied (90%)
Valve systems including SSIVs, choke and kill systems, and X-mas tree: Likely to be applied (90%)
Well pressure monitoring: Likely to be applied (90%)
Emergency plans, including spill clean-up: Likely to be applied (90%)</td></tr>
<tr><td rowspan="3">Sediments/benthic habitat</td><td>Coastal biodiversity/ habitat loss</td><td>Likelihood: Rare
Consequence: Catastrophic
Risk: 10 (High)</td><td>Likelihood: Likely
Consequence: Catastrophic
Risk: 20 (Very High)</td></tr>
<tr><td>Deterioration in water quality</td><td>Likelihood: Rare
Consequence: Moderate
Risk: 6 (Moderate)</td><td>Likelihood: Likely
Consequence: Catastrophic
Risk: 20 (Very High)</td></tr>
<tr><td>Sediment fouling</td><td>Likelihood: Rare
Consequence: Moderate
Risk: 6 (Moderate)</td><td>Likelihood: Occasional
Consequence: Major
Risk: 12 (High)</td></tr>
<tr><td rowspan="2">Discharges to sea: Accidental hydrocarbon spill - Tier II (requiring assistance from other Operator resources)
The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower</td><td rowspan="2">Subsea isolation valves
Process system monitoring
Spill clean-up procedures
Spill clean-up resources (marine and coastal) as well as potentially third party specialist spill response contractors.</td><td rowspan="2">Marine flora and fauna
Intertidal/coastal flora and fauna
Water quality
Sediments/benthic habitat</td><td>Marine biodiversity/ habitat loss</td><td>Likelihood: Rare
Consequence: Moderate
Risk: 6 (Moderate)</td><td>Likelihood: Occasional
Consequence: Major
Risk: 12 (High)</td><td rowspan="2">Valve systems including SSIVs, choke and kill systems, and X-mas tree: Likely to be applied (90%)
Emergency plans, including spill clean-up: Likely to be applied (90%)</td></tr>
<tr><td>Coastal biodiversity/ habitat loss</td><td>Likelihood: Rare
Consequence: Major
Risk: 8 (Moderate)</td><td>Likelihood: Occasional
Consequence: Catastrophic
Risk: 15 (Very High)</td></tr>
</table>

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			margins for operator error during production.			Deterioration in water quality	Likelihood: Rare Consequence: Minor Risk: 4 (Low)	Likelihood: Occasional Consequence: Major Risk: 12 (Very High)	
						Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Occasional Consequence: Moderate Risk: 9 (Moderate)	
			Discharges to sea: Accidental hydrocarbon spill – Tier I (can be dealt with by local Operator resources) The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment and lower margins for operator error during production.	Refer to 2.2.3: Discharges to sea, accidental hydrocarbon spill – Tier I (can be dealt with by local Operator resources) – Drilling	–	–	–	-	-
		3.2.4 Gas production, processing and handling	Releases to air: Accidental gas emissions during production In high winds, low temperatures and rougher seas there is greater stress on containment equipment, therefore containment failure of produced gas may be more likely.	Leak detection and repair programme Elimination of flanged connections to extent practicable. Valve and flange specifications.	Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: occasional Consequence: minor Risk: 6 (moderate)	Likelihood: Likely Consequence: minor Risk: 8 (moderate)	Leak detection and repair programmes: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Releases to air: Planned gas emissions, e.g. venting, during production	Design to avoid production venting	Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: occasional Consequence: moderate Risk: 9 (High)	Likelihood: Likely Consequence: moderate Risk: 12 (High)	Process design for gas to avoid need for venting: H Likely to be applied (90%)
			Releases to air: Unplanned venting of gas required for safety (e.g. process system blowdown)	Design to avoid production venting	Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	
		3.2.5 Produced water management	Discharges to sea: Accidental release of untreated PW to sea (containing residual hydrocarbons, production chemicals and reservoir contaminants) In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of untreated produced water may be more likely.	Topsides PW treatment to meet relevant oil-in-water standards (e.g. typically <40 mg/l) Testing and analysis prior to discharge Modelling of PW discharge during design	Marine flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	Likelihood: Highly Likely Consequence: Minor Risk: 10 (High)	Treatment and analysis systems for PW and oil content: Likely to be applied (90%)
						Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	
						Deterioration in water quality	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	
						Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Planned discharge of treated PW to sea (containing residual hydrocarbons, production chemicals and reservoir contaminants)	Designed integrity and redundancy in PW injection system	Marine flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: highly likely Consequence: Slight Risk: 5 (Moderate)	Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	Treatment and analysis systems for PW and oil content: Likely to be applied (90%)
						Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Occasional Consequence: Slight Risk: 4 (low)	
						Deterioration in water quality	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	
						Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	
		3.2.6 Produced sand management	Discharges to sea: Accidental loss of produced sand to sea (e.g. during transfer to support vessel) Similar to a planned disposal of sand but with higher consequences	Subject to permit and approval following clean up treatment Avoidance through onshore disposal	Marine flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Occasional Consequence: Slight Risk: 3 (low). No change as measures cannot reduce the risk any further.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Treatment and analysis systems for PW and oil content: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of untreated produced sand may be more likely.			Deterioration in water quality	Likelihood: Occasional Consequence: Slight Risk: 3 (low). No change as some degree of water quality damage is unavoidable with these practices.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	
						Sediment fouling/benthic habitat smothering	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate). No change as measure may not be applied and this practice has an unavoidable impact on the seabed.	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	
			Discharges to sea: Planned disposal of produced sand to sea	Subject to permit and approval following clean up treatment Avoidance through onshore disposal	Marine flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Occasional Consequence: Slight Risk: 3 (low). No change as measures cannot reduce the risk any further.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Treatment and analysis systems for PW and oil content: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
						Deterioration in water quality	Likelihood: Occasional Consequence: Slight Risk: 3 (low). No change as some degree of water quality damage is unavoidable.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	
						Sediment fouling/benthic habitat smothering	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate). No change as measures may not be applied and do not have a significant effect on the consequence of this impact.	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	
		3.2.7 Off-gas management - flaring	Releases to air: Unplanned flaring of gas for safety purposes (process blowdown) (NOx, SOx, GHG)	Flaring emissions (NOx, SOx, GHG, smoke) Design for no production flaring (off-gas recovery, flare gas recovery, process design)	Local flora and fauna	Local air quality pollution	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	
					Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	Likelihood: Occasional Consequence: Moderate Risk: 9 (moderate)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Releases to air: Planned flaring of off-gas for production (NOx, SOx, GHG)	Flaring emissions (NOx, SOx, GHG, smoke) - Drilling Flare design (high efficiency, low smoke)	Local flora and fauna	Local air quality pollution	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	
					Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Likely Consequence: Moderate Risk: 12 (high)	Likelihood: Likely Consequence: Major Risk: 16 (Very high)	
		3.2.8 Power generation and combustion equipment	Releases to air: Emissions from power generation/turbines/process systems Production users dependent upon centralised power include pumps, valves, centrifuges, compressors, heaters, etc.	BAT study during platform design for choice of generators Maintenance of power generation equipment Emissions regulatory reporting requirements Waste heat recovery and integrated plant efficiency Equipment specification Optimisation of power demand	Atmosphere	Local air quality - pollution	Likelihood: Rare Consequence: Sight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Maintenance programs for all equipment: Likely to be applied (90%)
						Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: likely Consequence: Slight Risk: 4 low	Likelihood: Highly Likely Consequence: Slight Risk: 5 (Moderate)	
			Releases to air: Emissions from combustion equipment other than GTGs (e.g. turbine compressor drivers, fired	Equipment specification Optimisation of power demand Permitting requirements (PPC etc.)	Atmosphere	Local air quality - pollution	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Maintenance programs for all equipment: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			heaters, EDGs, diesel firewater pumps)			Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: occasional Consequence: Slight Risk: 3 (low)	Likelihood: occasional Consequence: Minor Risk: 6 (Moderate)	
		3.2.9 Hydrocarbon and chemical storage	Accidental hydrocarbon spill – Tier III (requiring assistance from third party resources) Discharges to sea: Accidental loss of containment of hydrocarbon cargo to sea May result from: - Ship collision - Equipment/structural failure - Human error The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment	Hull/topsides designed to provide protection to storage tanks from collision. Use of drip-pans and drainage systems including oil separation systems (Ffyne, Mariner & Ythan) Safety exclusion zone Nav-aids	Marine flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Extremely Rare Consequence: Major Risk: 4 (Low)	Likelihood: Rare Consequence: Catastrophic Risk: 10 (High)	Emergency plans, including spill clean-up: Likely to be applied (90%)
						Coastal biodiversity/ habitat loss	Likelihood: Extremely Rare Consequence: Catastrophic Risk: 5 (Moderate)	Likelihood: Rare Consequence: Catastrophic Risk: 10 (High)	
						Deterioration in water quality	Likelihood: Extremely Rare Consequence: Major Risk: 4 (Low)	Likelihood: Rare Consequence: Catastrophic Risk: 10 (High)	
						Sediment fouling	Likelihood: Extremely Rare Consequence: Major Risk: 4 (Low)	Likelihood: Rare Consequence: Major Risk: 8 (Moderate)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Accidental hydrocarbon spill - Tier II (requiring assistance from other Operator resources) Discharges to sea: Accidental loss of containment of hydrocarbon cargo to sea May result from: - Ship collision - Equipment/structural failure - Human error The likelihood of accidental discharges may increase when the rig is located in deeper and rougher waters. This is because there is greater stress put on containment equipment			Marine biodiversity/ habitat loss	Likelihood: Rare Consequence: Moderate Risk: 4 (Low)	Likelihood: Rare Consequence: Major Risk: 8 (moderate)	
						Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Moderate Risk: 4 (Low)	Likelihood: Rare Consequence: Major Risk: 8 (moderate)	
						Deterioration in water quality	Likelihood: Rare Consequence: Moderate Risk: 4 (Low)	Likelihood: Rare Consequence: Major Risk: 8 (moderate)	
						Sediment fouling	Likelihood: Rare Consequence: Moderate Risk: 4 (Low)	Likelihood: Rare Consequence: Major Risk: 8 (moderate)	
		3.2.10 Diesel/chemical deliveries/loading	Discharges to sea: Accidental loss of containment during hydrocarbon offtake by offtake tanker The likelihood of accidental discharges may increase when the rig is located in rougher waters and high winds. This is because there is greater	Discharges to sea, accidental hydrocarbon spill – Tier I (requiring assistance from third party resources) – Drilling Training for all personnel, quick release valve mechanisms that can be operated remotely. Drip-pans and	Marine flora and fauna Intertidal/coastal flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Rare Consequence: Moderate Risk: 6 (Moderate)	Likelihood: Occasional Consequence: Major Risk: 12 (High)	Emergency plans, including spill clean-up: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			stress put on containment equipment and less margin for operator error during loading/unloading	drainage systems including oil separation.		Coastal biodiversity/ habitat loss	Likelihood: Rare Consequence: Major Risk: 8 (Moderate)	Likelihood: Occasional Consequence: Major Risk: 12 (High)	
						Deterioration in water quality	Likelihood: Rare Consequence: Minor Risk: 4 (Low)	Likelihood: Occasional Consequence: Major Risk: 12 (Very High)	
						Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Occasional Consequence: Moderate Risk: 9 (Moderate)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		3.2.11 Open loop seawater cooling of process and utility systems	Discharges to sea: Planned discharge of cooling water to sea: thermal pollution	Design of process systems to minimise cooling requirement Winning cooling water from depth (i.e. colder water) Design/depth of discharge location	Marine flora and fauna Water quality	Behavioural response in marine fauna Biodiversity	Likelihood: Likely Consequence: Slight Risk: 4 (low). No change as measures have little effect on this risk.	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Design and management of systems for cooling: Likely to be applied (90%)
			Discharges to sea: Unplanned discharge of cooling water to sea: residual anti-foulant In high winds, low temperatures and rough seas there is greater stress on equipment, therefore accidental discharges of residual anti-foulant may be more likely.	Use of non-persistent inorganic anti-foulant (typically hypochlorite) Design of dosing system to minimise effective concentration	Marine flora and fauna Water quality	Behavioural response in marine fauna	Likelihood: Likely Consequence: Slight Risk: 4 (low).No change as measures may not be applied and have only effect on consequence.	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Refer to 2.2.3, use of low risk/hazard chemicals
		3.2.12 HVAC systems	Releases to air: Unplanned release of greenhouse gases to atmosphere (leakage of refrigerant gases from HVAC and refrigerant systems) In high winds, low temperatures and rough seas there is greater stress on equipment, therefore accidental discharges of HVAC fluids may be more likely.	Compliance with the EU Fluorinated gases regulation (EC/ 517/2014)	Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Likely Consequence: Slight Risk: 4 (low)	Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	Design and management of systems for cooling: Likely to be applied (90%)

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		3.2.13 Topsides drainage systems	Discharges to sea: Planned discharge to sea of treated topsides drainage flows	Refer to 2.2.3: Discharges to sea, residual chemical additives/ hydrocarbons to sea (planned release) Refer to 2.2.3: Discharges to sea, accidental hydrocarbon spill – Tier I (can be dealt with by local Operator resources) Provision of oil/water treatment systems to comply with discharge performance standards Testing prior to discharge for batch-controlled discharge Online oil in water measurements for continuous systems	–	–	–	-	-
		3.2.14 Waste management	Discharges to sea: Accidental loss of liquid wastes to sea during transfer to support vessel for onshore disposal In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of waste may be more likely.	Design of liquid waste transfer/handling equipment Design of waste (closed-skin skips, bins, IBCs, containers etc.) to prevent loss. Liquids handling procedures Sealed tote tanks	Marine flora and fauna Water quality Sediments/benthic habitat	Marine biodiversity/ habitat loss	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Refer to 2.2.1, transport of drilling rig
						Deterioration in water quality	Likelihood: Rare Consequence: Sight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	
						Sediment fouling/benthic habitat smothering	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Accidental loss of solid wastes to sea during transfer to support vessel for onshore disposal In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of waste may be more likely.	Waste management planning Design of solid waste transfer/handling equipment Design of waste (skips, bins, IBCs, containers etc.) Solids handling procedures	Marine flora and fauna	Marine biodiversity/ habitat loss	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate). No change as some discharge is unavoidable, due to the scale of operations.	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	Refer to 2.2.1, transport of drilling rig in
					Sediments/benthic habitat	Sediment fouling/benthic habitat smothering	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate). No change as some discharge is unavoidable, due to the scale of operations.	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	
		3.2.15 Oil offtake – Vessel	Discharges to sea: Accidental loss of containment during hydrocarbon offtake by offtake tanker In high winds and rough seas there is and greater stress on equipment, therefore accidental discharges of oil during offtake may be more likely.	Refer to 3.2.9; Discharges to sea, accidental hydrocarbon spill – Tier III (requiring assistance from third party resources) – Drilling Training for all personnel, quick release valve mechanisms that can be operated remotely. Drip-pans and drainage systems including oil separation.	–	–	–	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		3.2.16 Oil export pipeline/tie in equipment	Discharges to sea: Loss of containment of crude from export pipeline In and rough seas and deeper waters there is and greater stress on the pipeline, therefore loss of containment may be more likely.	Refer to 3.2.3: releases to water, accidental hydrocarbon spill – Tier III (requiring assistance from third party resources) – Drilling	–	–	–	-	-
		3.2.17 Gas export pipeline/tie in equipment	Releases to air: Rupture of gas export pipeline leading to atmospheric emissions Consequences would depend on the period for which a release went undetected In rough seas and deeper waters there is and greater stress on the pipeline, therefore loss of containment may be more likely.	Pipeline design Pipeline isolation/shut-in Leak detection systems Pipeline inspection and maintenance programme	Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Refer to 3.2.4, use of leak detection and repair systems
		3.2.18 Water flooding using seawater	Discharges to sea: Planned discharge of additional treated PW to sea resulting from water flooding (containing residual hydrocarbons, production chemicals and reservoir contaminants)	Refer to 3.2.5: Discharges to sea, planned and accidental discharges of treated PW Refer to relevant measures in 1.1.1:					-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Accidental release of untreated PW to sea (containing residual hydrocarbons, production chemicals and reservoir contaminants) underwater noise: in the marine environment resulting from induced seismicity In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of untreated produced water may be more likely.	underwater noise, seismic activity					
			Releases to air: increased emissions of greenhouse gases and local air quality pollutants as a result of additional power generation for filtration, pressurisation and injection systems.	Refer to 1.1.1 and 2.2.1: Releases to air, emissions from marine transport (CO, CO2, NOx and SOx, etc.)	-	-	-	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		3.2.19 Enhanced recovery using injection of miscible produced hydrocarbons gas	Releases to air: increased emissions of greenhouse gases and local air quality pollutants as a result of additional power generation for filtration, pressurisation and injection systems. underwater noise: in the marine environment resulting from induced seismicity	Releases to air: Refer to 1.1.1 and 2.2.1: emissions from marine transport (CO, CO2, NOx and SOx, etc.) Refer to relevant measures in 1.1.1: underwater noise, seismic activity	- -	-	-	-	
		3.2.20 Well stimulation using low volume hydraulic fracturing	Releases to air: increased emissions of greenhouse gases and local air quality pollutants as a result of additional power generation for filtration, pressurisation and injection systems.	Refer to 1.1.1 and 2.2.1: Releases to air, emissions from marine transport (CO, CO2, NOx and SOx, etc.)	-	-	-	-	-
			Discharges to sea: Planned discharge of flowback to sea resulting from water flooding (containing residual hydrocarbons, production chemicals and reservoir contaminants)	Refer to 3.2.5: Discharges to sea, planned and accidental discharges of treated PW	-	-	-	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Discharges to sea: Accidental release of flowback to sea (containing residual hydrocarbons, production chemicals and reservoir contaminants) In high winds and rough seas there is a lower margin for operator error and greater stress on equipment, therefore accidental discharges of untreated flowback may be more likely.	Refer to 3.2.5: Discharges to sea, planned and accidental discharges of treated PW	-	-	-	-	-
			Discharges to sea: accidental loss of containment of chemical/ proppant storage on the rig. In high winds, rough seas and low temperatures there is greater stress on equipment, therefore loss of containment may be more likely.	Refer to 2.2.3: Accidental hydrocarbon spill – Tier I	-	-	-	-	-
			Underwater noise: resulting from induced seismicity due to underground hydraulic fracturing (disturbance to animals)	Refer to relevant measures in 1.1.1: underwater noise, seismic activity	-	-	-	-	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
4. Project cessation and well closure	4.1 Well Closure	4.1.1 Well plug and abandonment (P&A) Tubing recovery	Release to water: Chemicals used/encountered during decommissioning process In rough seas, high winds and deep waters, the risk of discharges to sea during well plugging may increase as margins for error are lower.	Comprehensive decommissioning plan in place Refer to 2.2.3: Discharges to sea of residual chemicals.	Marine flora and fauna Sediments/benthic habitat	Release of residual contaminated fluids.	Likelihood: Extremely rare Consequence: Slight Risk: 1 (low)	Likelihood: Extremely rare Consequence: Minor Risk: 2 (low)	Refer to 2.2.3, use of low risk/hazard chemicals
			Underwater noise: Noise during cutting of subsea infrastructure	Refer to 2.2.3: Underwater noise from drilling	Marine flora and fauna	Generation of underwater noise causing potential disturbance to marine life	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: occasional Consequence: Minor Risk: 6 (Moderate)	Refer to 2.2.3: Underwater noise from drilling
			Physical disturbance to seabed: Loss of minor /small items e.g. scaffold within 500m of the platform. In rough seas and high winds and deep waters, the risk of the loss of small items to sea may increase as margins for error are lower.	Post-decommissioning debris clearance operations	Sediment/benthic habitat	Physical disturbance to seabed and suspension of sediment into the water column.	Likelihood: Occasional Consequence: Slight Risk: 3 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	-

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		4.1.2 Management of cuttings pile, if present - Leave *in situ* with no removal or disturbance	Discharges to sea: Leaching of contaminants including hydrocarbon and metals into the water column from cuttings pile.	On-going long-term monitoring programme (see 2.4.1 – licensing for details on monitoring)	Sediments/benthic habitat Water column Marine flora and fauna	Potential release of toxic contaminants into the water column and seabed, which may impact pelagic and demersal species	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate). No change as measures may not be applied and the some contamination from the aspect is unavoidable.	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	On-going monitoring[7] by operators and as required with independent reviews by competent authorities post closure: Possible to be applied (40%)
		4.1.3 Management of cuttings pile, if present - Excavation of cuttings pile and recovery to surface/redistribution to another area of seabed.	Emissions to air: Power generation for excavation of the pile and recovery to surface.	Refer to 3.2.8. BAT measures for power generation equipment and marine shipping Maintenance of power generation equipment	-	-	-	-	-

[7] subject to the decision of competent authorities

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
5. Post closure and abandonment	5.1 Topside and jacket decommissioning	5.1.1 Power generation for - the manufacture of temporary steelwork, - dismantling structures inshore - module separation and cutting - onshore transportation of recovered material to recycling site or landfill facility	Emissions to air: Power generation for all topside decommissioning activities with potential for releases to air as exhaust fumes.	Refer to 3.2.8. Maintenance of power generation equipment BAT measures for power generation equipment	Atmosphere	-	-	-	-
		5.1.2 Topside/jacket preparation for removal using hot cutting, welding etc.	Discharges to sea: generation of material, dust and metallic structure discharges onto the sea surface/water column. In rougher seas, high winds and cold temperatures, the chances of accidental discharges to sea may be higher, as there are lower margins for error.	Comprehensive decommissioning plan in place Containment procedures for air/water releases.	Marine flora and fauna	Release of potentially toxic contaminants into the water column and seabed	Likelihood: Rare Consequence: Slight Risk: 2 (low). No change as measures cannot reduce the likelihood another further	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Refer to 2.2.1, use of bunding, protected skids and totes

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Seabed disturbance: Physical disturbance to the seabed and cuttings pile, if present from dropped objects, e.g. Module loss during lifting and transportation, loss of metal debris. In rougher seas, high winds and cold temperatures, the chances of additional seabed disturbance caused by dropped equipment may be higher, as there are lower margins for error.	Detailed lifting procedures	Sediments/benthic habitats Marine flora and fauna	If present, disturbance to cuttings pile may potentially release toxic contaminants to the water column and seabed	Likelihood: Extremely rare Consequence: Moderate Risk: 3 (Low). No change as measures cannot reduce the likelihood any further	Likelihood: Extremely rare Consequence: Moderate Risk: 3 (Low)	Refer to 2.2.3, lifting procedures under drilling using WBM
			Underwater noise: cutting of jacket/topside to facilitate removal	Refer to 2.2.3: underwater noise from drilling Planned efficient cutting regime to achieve as few cuts as possible.	Marine fauna	Behavioural responses in marine fauna.	Likelihood: Likely Consequence: Slight Risk: 2 (low)	Likelihood: Highly Likely Consequence: Slight Risk: 3 (low)	Refer to 2.2.3: underwater noise from drilling
	5.2 Decommissioning seabed infrastructure, e.g. pipelines/bundles	5.2.1 Power generation for dismantling structures inshore.	Emissions to air: Power generation	Refer to 3.2.8, emissions to air	Atmosphere	-	-	-	-
		5.2.2 Leave pipeline/sections in place Rock placement	Seabed disturbance: Physical disturbance causing suspension of material. In deeper and rougher waters, rock dumping may be more inaccurate, resulting in an increased likelihood of seabed disturbance.	Minimise rock material placement.	Sediments/benthic habitats	Sediment fouling/ smothering of benthic flora and fauna	Likelihood: Occasional Consequence: Moderate Risk: 9 (high). No change as seabed disturbance from this process is unavoidable.	Likelihood: Occasional Consequence: Moderate Risk: 9 (high)	Refer to 3.1.4

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
		5.2.3 Remove mattresses, sand bags, grout bags, and frond mats. Water jet rock dump to expose line	Underwater noise: Generation of underwater noise disturbance.	Planning of construction activities to avoid sensitive time periods etc. Noise modelling propagation models to assess impact.	Marine fauna	Behavioural responses in marine fauna.	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Likelihood: Likely Consequence: Minor Risk: 8 (Moderate)	Refer to 1.1.1
	5.3 Shipping activities for all processes in life-cycle stage 5	5.3.1 Shipping activities for all processes in life-cycle stage 5	Releases to air: Emissions from surveying vessels (CO, CO_2, NOx and SOx, etc.) Pollution levels considered consistent with typical shipping operations worldwide, risk presented here is on the basis of per campaign.	Per standard marine shipping measures for vessel pollution. Many of offshore environmental assessments include impact assessment for air pollution and greenhouse gas emissions as part of a development. This includes carbon footprints and measures to reduce fuel consumption where possible (Ffyne, Kew, Edradour & Peterhead).	Local flora and fauna	Local air pollution	Likelihood: Rare Consequence: Slight Risk: 2 (low). No change as measure may not be adopted and the risk is so low that measures cannot reduce it any further.	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Refer to 2.2.1, transport of the drilling rig
					Atmosphere	Contribution to global emissions (climate change, sea acidification, etc.)	Likelihood: Likely Consequence: Slight Risk: 4 (low). No change as measures may not be adopted and only abate a proportion of emissions when they are adopted.	Likelihood: Likely Consequence: Slight Risk: 4 (low)	

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			Anchoring on seabed may cause scouring across the seabed surface as chains used to hold in place whip across the surface. In rough seas anchoring may cause more damage to the seabed, as it is dragged across a greater area.	Anchor plan informed by site surveys	Sediments/benthic habitats Marine flora and fauna	Physical disturbance to seabed and suspension of sediment into the water column.	Likelihood: Likely Consequence: Slight Risk: 4 (Low). No change as the physical disturbance from anchoring cannot be avoided.	Likelihood: Likely Consequence: Slight Risk: 4 (Low)	Refer to 3.2.2
			Discharges to sea (containment failure on shipping) In rough seas and high winds containment failures on shipping and the rig may be more likely due to decreased margins for operator error and stress on equipment.	Spill clean-up procedures Spill clean-up resources (marine and coastal) Hazardous chemicals stored in designated areas with bunding and drain systems to contain leaks. Quick-release valves for remotely detaching during decanting/hose operations. Spill response plans and training for personnel to respond quickly during an incident. Visual checks of equipment and general maintenance to look for any hose line issues in advance.	Sediments/benthic habitats Marine flora and fauna Stakeholders	Release of fuel oil into the marine environment.	Likelihood: Occasional Consequence: Minor Risk: 6 (Moderate)	Likelihood: Occasional Consequence: Moderate Risk: 9 (High)	Refer to 2.2.3, emergency plans for oil spill procedures
			Discharges to sea (containment failure on rig) In rough seas and high winds containment failures on shipping and the rig may be more likely due to decreased margins for operator error and stress on equipment.		Sediments/benthic habitats Marine flora and fauna Stakeholders	Release of fuel oil into the marine environment.	Likelihood: Rare Consequence: Slight Risk: 2 (low)	Likelihood: Rare Consequence: Minor Risk: 4 (low)	
	5.4 Long-term well integrity	14.1 Well integrity failure and monitoring	Discharges to sea (accidental) - leakage of hydrocarbon liquids from the well into the ocean Releases to air (contributions to climate	Monitoring of well integrity post closure	Atmosphere Marine flora and fauna	Releases of hydrocarbons into the marine environment Contributions to climate change	Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Rare Consequence: Moderate Risk: 6 (moderate)	On-going monitoring[8] by operators and as required with independent reviews by

[8] subject to the decision of competent authorities

Stage	Sub-stage	Processes/technologies	Environmental Aspect	Expected management measures	Receptor	Impacts	Risk level (with expected management measures in place)	Risk level (without expected management measures in place)	Level of uptake for measures detailed[1]
			change) (accidental) – methane leakage into the atmosphere				Likelihood: Rare Consequence: Minor Risk: 4 (low)	Likelihood: Occasional Consequence: Minor Risk: 6 (moderate)	competent authorities post closure: Possible to be applied (40%)[9]

[9] Based on the findings in Davies et al (2014) that to the best of their knowledge, post-closure monitoring is not carried out at all the UK, this may be an overestimate. However, there are several industry guidance documents which make reference to post-closure monitoring including OGP (1997), IGEM (2013) and IFC (2007). Additionally, the scope of the findings in the Davies et al (2014) study are limited relevant to this report, because they refer to only one jurisdiction within the EU. On this basis, the judgement that the measure is 'possible be applied (40%)' has been maintained.

Appendix C
European offshore conventions

Barcelona Convention: The Convention for the Protection of Marine Environment and the Coastal Region of the Mediterranean of 1995 (further to the earlier version of 1976) – the Barcelona Convention (UNEP-MAP). Contracting parties include: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, the European Community, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia, and Turkey.

Bucharest Convention: The Convention for the Protection of the Black Sea of 1992 – the Bucharest Convention. Contracting parties include: Bulgaria, Georgia, Romania, Russian Federation, Turkey and Ukraine.

MARPOL Convention: International Convention for the Prevention of Pollution from Ships. Adopted 1973 in the International Maritime Organization. The main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. Annexes include approx. 150 contracting states/parties.

HELCOM: The Convention on the Protection of the Marine Environment in the Baltic Sea Area of 1992 (further to the earlier version of 1974) – the Helsinki Convention (HELCOM). Contracting parties include: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The European Union is also a party to this convention.

OSPAR: The Convention for the Protection of the Marine Environment in the North-East Atlantic of 1992 (further to earlier versions of 1972 and 1974) – the OSPAR Convention (OSPAR). Contracting parties include: Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland) along with Luxembourg and Switzerland. It covers 5 regions: Region I: Arctic Waters, Region II: Greater North Sea, Region III: Celtic Seas, Region IV: Bay of Biscay/Iberian Coast, Region V: Wider Atlantic.

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