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Economic and Policy Perspectives in Health, Safety and Environment in the Offshore Oil and Gas Industry: Evidence from the United Kingdom Continental Shelf

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Research in North Sea Economics has been conducted in the Economics Department since 1973. The present and likely future effects of oil and gas developments on the Scottish economy formed the subject of a long term study undertaken for the Scottish Office. The final report of this study, The Economic Impact of North Sea Oil on Scotland, was published by HMSO in 1978. In more recent years further work has been done on the impact of oil on local economies and on the barriers to entry and characteristics of the supply companies in the offshore oil industry.

The second and longer lasting theme of research has been an analysis of licensing and fiscal regimes applied to petroleum exploitation. Work in this field was initially financed by a major firm of accountants, by British Petroleum, and subsequently by the Shell Grants Committee. Much of this work has involved analysis of fiscal systems in other oil producing countries including Australia, Canada, the United States, Indonesia, Egypt, Nigeria and Malaysia. Because of the continuing interest in the UK fiscal system many papers have been produced on the effects of this regime.

From 1985 to 1987 the Economic and Social Science Research Council financed research on the relationship between oil companies and Governments in the UK, Norway, Denmark and The Netherlands. A main part of this work involved the construction of Monte Carlo simulation models which have been employed to measure the extents to which fiscal systems share in exploration and development risks.

Over the last few years the research has examined the many evolving economic issues generally relating to petroleum investment and related fiscal and regulatory matters. Subjects researched include the economics of incremental investments in mature oil fields, economic aspects of the CRINE initiative, economics of gas developments and contracts in the new market situation, economic and tax aspects of tariffing, economics of infrastructure cost sharing, the effects of comparative petroleum fiscal systems on incentives to develop fields and undertake new exploration, the oil price responsiveness of the UK petroleum tax system, and the economics of decommissioning, mothballing and re-use of facilities. This work has been financed by a group of oil companies and Scottish Enterprise, Energy. The work on CO2 Capture, EOR and storage was financed by a grant from the Natural Environmental Research Council (NERC) in the period 2005 – 2008.

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Economic and Policy Perspectives in Health, Safety and Environment in the Offshore Oil and Gas Industry: Evidence from the United Kingdom Continental Shelf

Professor Alexander G. Kemp and Theophilus Acheampong

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1 Introduction: Health, Safety and Environment in the Offshore Oil and Gas Industry

Health, Safety and Environment (HSE) compliance is an essential component of any industry, and more so, in the offshore oil and gas industry, where the inherent risks associated with operating under challenging conditions are high. Workplace accidents, injuries and environmental releases in the offshore oil and gas industry impose economic costs on operators, employees and the wider society. It is also the case that most of these costs are sometimes external to the operators and employers. Effective and efficient management of HSE issues is now a priority for oil and gas operators, government regulators, employers and civil society groups. Events such as the 2010 Macondo Blowout and Explosion in the US Gulf Coast have brought to the fore the interrelationship between HSE management and the financial performance and productivity of the industry. For example, the total monetary compensation package from the Macondo Accident in the US Gulf Coast cost BP and its partners close to US$65 billion.

Even though the oil and gas industry's safety and environmental record have improved significantly with the advent of newer technologies and improved risk perceptions, concerns exist amongst some stakeholders over whether the industry's current safety performance is adequate. These concerns are driven in part by the oil and gas industry's renewed attempts to extract hydrocarbons at greater water depths and in new frontier regions such as the Arctic (Tarantola et al., 2019; Fjørtoft and Berg, 2020 and Khan et al., 2015). The shift to ultra-deepwater operations implies a need for extra HSE investments by operators as well as enhanced regulatory measures to maintain or better the current standards.

It is important then to understand how the application of risk-based concepts to HSE issues could allow the industry to define what the optimal and tolerable levels of risk should be, given the ever-increasing regulatory environment. Legislative actions are undertaken by regulators to achieve the two main objectives: reduce the frequency and severity of work-related injuries, accidents and environmental spills, and provide more equitable compensation to victims of these accidents (Health and Safety Executive, 2020; Tombs and Whyte, 2010; Oi, 1974). As such, an overall public policy of reducing accidents, incidents and environmental releases would lead to enhanced welfare at a socially optimal level where the total HSE costs are minimised (Oi, 1974).

In the United Kingdom, the oil and gas industry's contribution to the economy and in meeting the nation's primary energy needs makes it imperative to consider the economic and policy implications of HSE issues on the industry's long-term prospectivity. Together, oil and gas accounts for 75% of the UK's primary energy demand, and over 50% of this demand is met by production from the United Kingdom Continental Shelf (UKCS) (Oil and Gas UK, 2020). HM Government estimates that oil and gas will continue providing over 60% of primary energy requirement by 2035 (Oil and Gas UK, 2020). Sustained production from the UKCS will be critical to enhancing the UK's security of energy supply. Therefore, the national policy objective of maximising the economic recovery (MER) of oil and gas reserves in a mature basin such as the UKCS must involve an understanding of the inherent HSE risks in offshore oil and gas operations and its economic implications.

This paper contributes to the HSE debate by offering a systematic review of HSE policy and the performance of the offshore oil and gas industry. We use the UKCS as one of the best practice exemplars on the measurement of HSE outcomes to understand how HSE investments by oil and gas operators as well as enhanced regulatory initiatives, can collectively contribute to maintaining or improving standards, thereby reducing associated economic and social costs of accidents and incidents. This is done through theoretical and empirical analysis, namely, by characterising an economic approach for evaluating HSE investments and undertaking a comparative statistical analysis of the trends in industry performance. The rest of the paper is structured as follows, **Section 2** reviews the economic approach to HSE, looking at some of the principles for evaluating HSE investment. The types of costs as well as the impact are discussed in **Section 3** and **Section 4**. In **Section 5,** we analyse the HSE performance of the United Kingdom's offshore oil and gas industry. Specifically, we focus on understanding the extent to which various investments and government-industry initiatives have contributed to improving the industry's HSE performance. Some of these initiatives have centred on reducing the numbers and severity of accidents, incidents, injuries and fatalities as well as reducing environmental and hydrocarbon releases (HCRs). We conclude in **Section 6**.

2 The Economic Approach to Health, Safety and the Environment

The economic approach to HSE has often been one in which HSE compliance is perceived as costly regarding the time and effort it takes to identify risks and put in place mitigating strategies. Instead, we believe that the approach should be seen from the perspective that making the right HSE investments can benefit the operator and society by having in place an assessment of the probability of an incident occurring. This allows stakeholders to put in place the necessary contingency or mitigation plans. In this regard, a cost-benefit approach provides a sound basis for evaluating HSE investment decisions in response to meeting set regulatory compliance standards. From a public policy perspective, HSE is considered a public good, being non-rival and non-excludable, and the market may not always efficiently provide for it (Horne, 2019). Society places positive values on reduced injuries, cleaner water and lower emissions.

Despite its public goods attributes, the value that society places on HSE can sometimes not be readily measured as that is often subjectivity. Valuations attached to these are captured by their Willingness-to-Pay (WTP) and Willingness- to-Accept (WTA) (Health and Safety Executive, 2000). The WTP and WTA approach to valuing safety allows us to discover the extent to which society is willing to pay or accept improvements to its collective safety and environmental wellbeing. This raises questions about how monetary values associated with health, safety and the environment should be defined and estimated for use in the offshore oil and gas context. Formal assessments using the costs and benefits involved in introducing HSE regulations, incorporate the WTP and WTA concepts as components in the calculations. For example, The United Kingdom's Health and Safety Executive (HSE) in its policy document notes "... cost-benefit analysis (CBA) offers a framework for balancing the benefits of reducing risk against the costs incurred in a particular option for managing risks."[1]

The values of health, safety and the environment should reflect the rate at which society is willing to trade-off enhanced levels of safety against other desirables with limited resources (Health and Safety Executive, 2000). However, significant disparities can exist between society's willingness to pay (WTP) for a small increase in their allocation of health, safety and environment benefits and the corresponding willingness to accept (WTA) a reduction of the same magnitude (Kahneman and Tversky, 1979; and Haneman, 1991). Standard economic theory

[1] See Health and Safety Executive 1999, Annex 3, Paragraph 8.

predicts that the allocation of these collective HSE benefits, which comes in the form of lower injuries, cleaner water and lower emissions, should differ only to a minor extent when valued with either the WTP or WTA (Chilton et al., 2010). The difference between the WTP and WTA for identical market goods is driven by the degree of substitution between them. For non-market goods such as reduced safety risks in an offshore oil and gas environment, imperfect substitutes do exist, and the divergence of the WTP and WTA will be persistent (Shogren et al., 1994). Given the preceding, the question that then arises is: how can we measure the WTP for the reduction of one unit of HSE risk?

The value of a statistical life (VSL) is a measurement of the willingness-to-pay (WTP) for one unit of mortality risk. This represents the value that society would be willing to pay for eliminating small probabilities of death (Viscussi and Aldy, 2003). Consider, for example, the offshore safety inspection initiative such as the United Kingdom's Deck and Drilling Operations (KP2)[2] programme which was expected to reduce the number of deaths during the next year by 1 for every 10,000 members of the offshore labour force. The ex-ante expectation is that this improvement would reduce each offshore worker's risk of premature death during the coming year by an average of 1 in 10,000. Suppose the industry is willing to pay £20,000 per member of the workforce to make the safety improvements.

This implies that for each death that is prevented, the industry will cumulatively pay £200 million – that is, £20,00 X 10,000 workers.

The WTP is based on this value of preventing the statistical fatality or injury (VPF) or the value of statistical life (VSL). This is given by the average of the

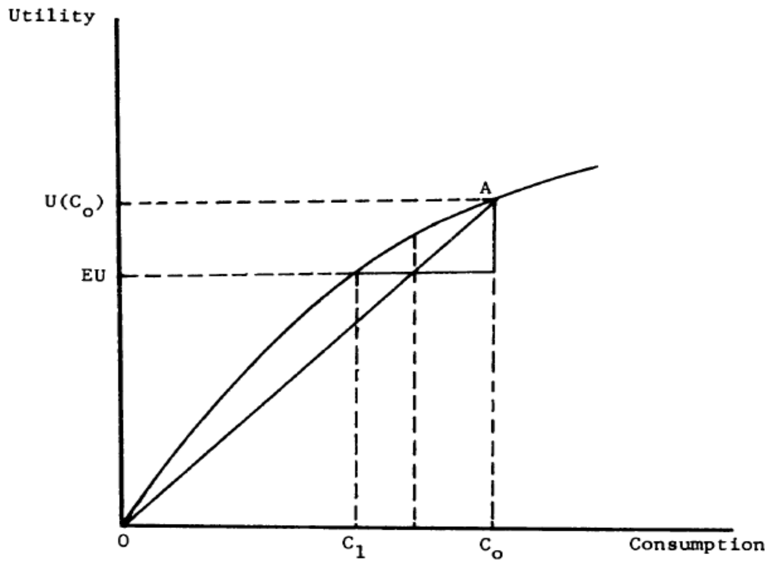
[2] The Deck and Drilling Operations Programme (KP2), programme was initiated in 2003 in response to unacceptable accident statistics from deck and drilling operations. The programme was reviewed in 2005, which resulted in a closer focus on the management of lifting operations within these two areas of activity, lifting operations having been seen to contribute significantly to fatalities and major injuries.

individual marginal rates of substitution of wealth for the risk of death or injury or health impairment concerned (Chilton, 2010). The WTP and WTA methodologies are also used for the evaluation of environmental quality. Three methodological approaches are used to derive WTP-based values of safety. These are the "revealed preference" (or "implied value"); the "contingent valuation" (or "expressed value"); and "relative valuation" (or "relativities") approaches (Health and Safety Executive, 2000).

Regarding the assessment of the contingent risks that form the basis of the WTP and WTA, the inherent risk of working offshore implies that some systematic risks cannot be eliminated. As such, the risk-free situation, as shown on point A in figure 1 below, where the offshore worker has an income associated with a consumption bundle CO and an associated utility[3] $U(CO)$ becomes unattainable. This is because the introduction of risk in the offshore working environment replaces this initial certain and risk-free prospect CO with an uncertain prospect in which the worker has a probability p of being injured or dying with zero income, and $(1-p)$ of getting the income CO (Dardis, 1980). Since death or injury is an undesirable state with zero utility, the expected utility of the offshore worker becomes a summation of the two probabilities weighted by the utility outcome. The expected utility is equal to $p(0)+(1-p)U(CO)= U(CO)+pU(CO)$. Hence, the oil and gas operator or employer must compensate the offshore worker for this loss in utility $pU(CO)$ for the risks associated with working offshore.

[3] Utility here implies the satisfaction or benefit that an offshore worker gains from consuming a given amount of goods or services with their wages.

Figure 1: Willingness-to-Pay and the Value of Life

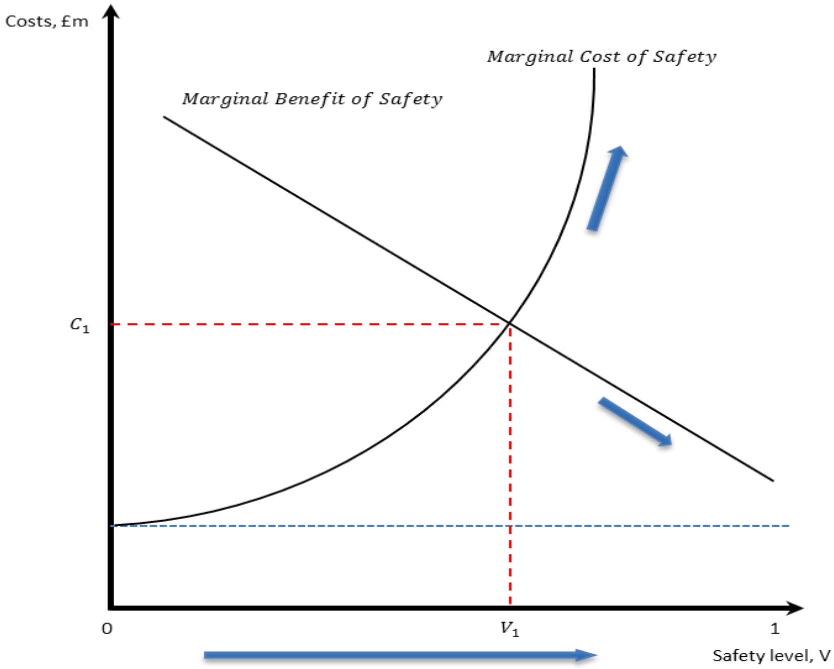


Adapted from Dardis (1980)

HSE Risk Optimisation

The probability of reducing accidents, incident rates or environmental releases is affected collectively by the actions of the employer, employees and the regulatory agencies. In some instances, the market places a premium on safety by differentially compensating for perceived job risks or hazards by factoring in higher wages for risky jobs. That is, if employees were fully aware of the workplace risks and could evaluate them, then a competitive labour market would ensure that, at the minimum, both stakeholders could derive an optimally balanced compensation for working in hazardous conditions (Pouliakas & Theodossiou, 2011; Dorman, 2000). The optimal safety perspective, which includes the operator's optimal investment in safety capital, and which is based on a standard model of profit maximisation, would occur at the point where the marginal benefits equal the marginal costs as shown in Figure 2 below.

Figure 2: Marginal Costs and Benefits of Increased Safety Level



Source: Author’s construct, based on Martinez and Miranda (2005)

As figure 2 illustrates, provided the incremental social costs are less than the incremental societal benefits, the imposition of liabilities or additional regulatory actions on the operator would be optimal. Generally, ex-post accidents, incidents and environmental spills or releases induce the industry to spend more on prevention costs to reduce the probability of future accidents. Higher investment in expenditures on safety and training, in turn, increase the marginal returns to prevention. However, even the ex-post characterisation and evaluation of the cost is often such that operators may still not be able to perceive the totality of the accident costs. This is because they sometimes underestimate the true costs or the estimation time horizon and scope become limited (Brody *et al.*, 1990). This, therefore, mandates the use of a sound cost-benefit analysis framework that has an accurate estimation of the costs as well as the benefits. Such a framework can, in turn, be effectively utilised to justify the need for investing in health, safety and the environment. Also, such a framework needs to depict the returns to the employer, employees and the society by lowering the expected social costs and externalities.

3 Health, Safety and Environment Costs

Factoring the costs of injuries, fatalities and environment releases into injury prevention models and analytical frameworks may be a useful, cost-effective tool from a public policy perspective. The ordinal preferences of the operator primarily determine the accuracy of the costs of safety decision making and the risks associated with offshore accidents and incidents. A breakdown of the cost structure in an offshore accident or release cost estimation model should, therefore, consider all parameters that reflect the possible costs which the accident is likely to impose (Gavious et al., 2009).

Using the framework developed by Brody *et al.* (1990), the total HSE cost can be analysed as a sum of two inputs: initial ***Prevention Costs (S)***, and Accident and ***Incidence Costs (I)***. Prevention Costs exist irrespective of the accident or incident rate and are the costs industry incurs ex-ante on machinery and equipment to meet the minimum regulatory standards before oil and gas production commences. The Accident and Incident Costs are the ex-post costs incurred after an accident, injury or environmental spill has occurred.[4] Generally, the consequences of an accident, injury or spill on the employer and industry are proportional to their ex-ante safety risk level. It can, therefore, be expected that an increment in the accident costs should evoke a reaction from the industry in the form of extra investments in safety to maintain or lower the accident risk level (Brody *et al.* 1990).

[4] Some components such as insurance costs, which are incurred at any given period, are included in the ex post accident costs because by purchasing an insurance policy, the employer transfers the obligation of making the necessary compensation for victims to the insurer.

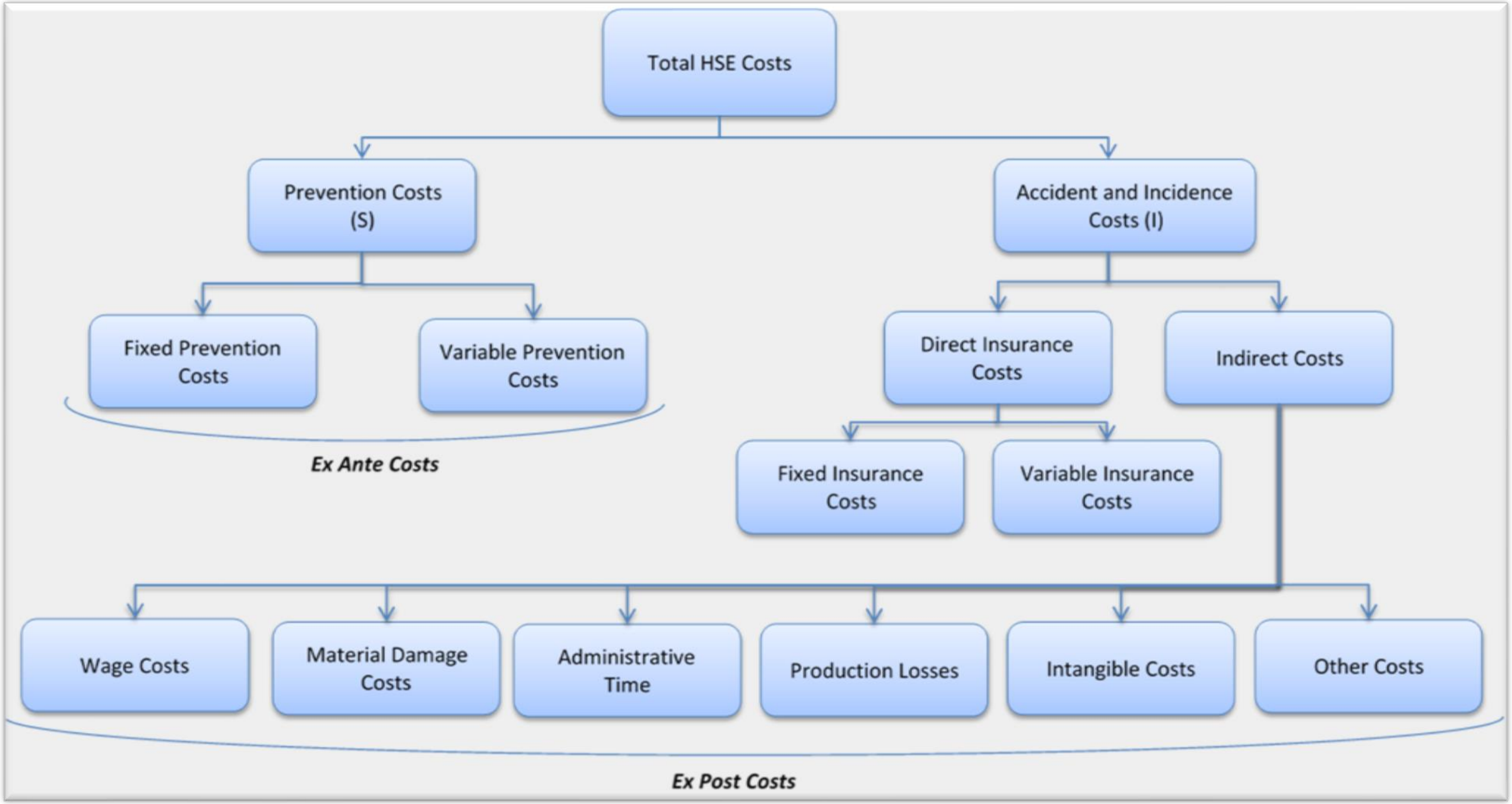
We thus end up with a cost model in which the total HSE costs are expressed as a relationship in the following equation:

$$Total\ HSE\ Costs\ \ =\ f\ (S, I) = \sum_{i=1}^{n} (S + I) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

$$where, \qquad S\ =\ Prevention\ Costs, and\ I\ =\ Accident\ and\ Incidence\ costs$$

The component breakdown of the Prevention (S), and the Accident and Incident Costs (I) are depicted in figure 3 below. The fixed prevention costs, which exist regardless of the accident rate in the industry, are costs incurred by the industry or employer before production from the offshore platform or field commences. These costs are dictated by policies set by the Health and Safety Executive or even by company HSE policy on the minimum standards that need to be maintained on the offshore facilities. It is important to note that the company HSE policy, which gives rise to the minimal fixed prevention costs cannot go lower than that set by the regulator. The variable prevention costs are proportional to accident or incident frequency and its severity. They include the time taken by HSE specialists to visit and inspect platforms and structures to identify causes and prescribe corrective measures. Other measures, such as training costs can be categorised as a variable prevention cost in response to the different training requirements.

Figure 3: Breakdown of the cost structure of offshore accidents and injuries



Source: Adapted from Brody *et al* (1990)

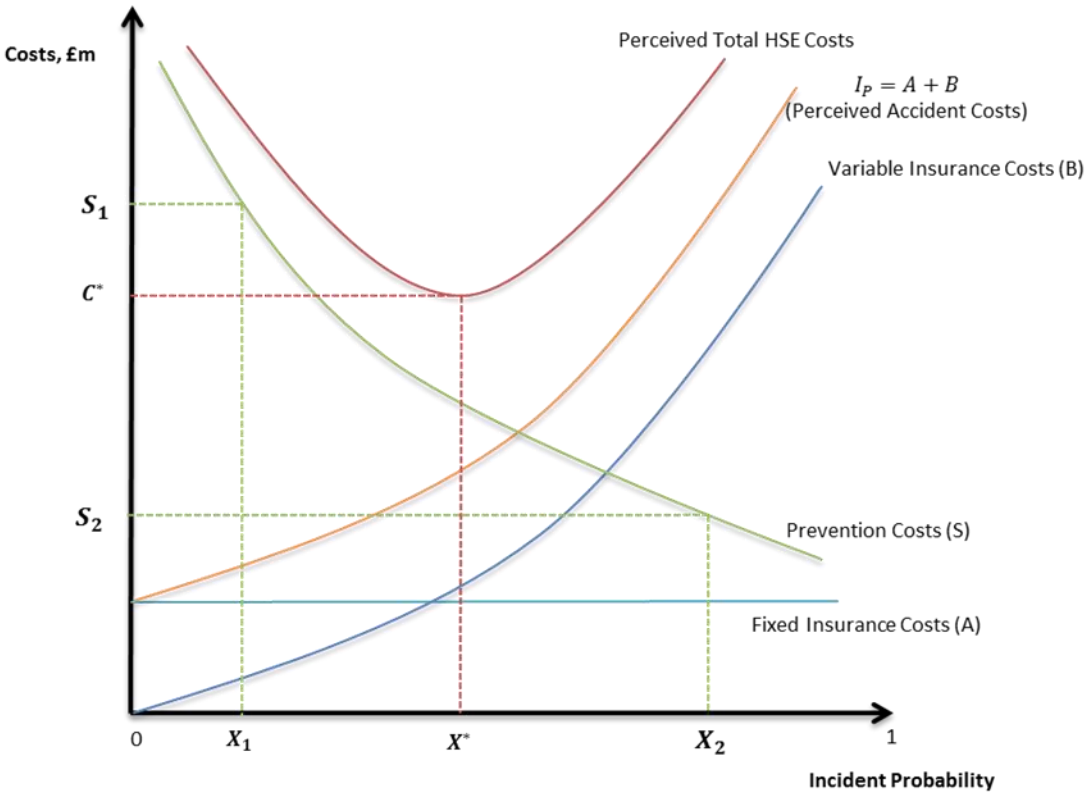
The Accident and Incident Costs (I) comprise the direct insurance costs as well as the indirect costs, which include the loss of value of production. National provisions mandate firms to purchase insurance to protect themselves against claims resulting from accidents, incidents and environmental spills or releases. The premiums paid, provide the company with a given level of cover that protects it against the risk of losses when an incident does occur. Largely dependent on the number and severity of accidents of the individual firm, firms have little control over the fixed insurance costs because they reflect in part the systematic risk of the probability of an incident occurring at the industry level (Brody *et al.*, 1990). The fixed insurance cost, however, does change in response to long-run industry conditions.

An experience rating based on an individual operator's riskiness accounts for the variable component of the insurance costs. Past accidents and incidents, statutory violations and notifications issued by the regulator form part of the basis used by a third-party insurer in computing the premiums that the employer pays. Companies that consistently invest in eliminating or making changes to their operational procedures to reduce the workplace risk, therefore, are likely to pay lower insurance premiums (*ceteris paribus*). The indirect cost component of the accident and incidence costs (I), includes wage costs, material damage, production losses and reputational damage.

Most employers and companies in the industry cannot accurately estimate total accident and incident costs because the indirect cost component such as the effect of reputational damage on the brand or shareholder valuation of the company take place only after the incident has occurred. The perceived costs by the industry, highlighted in figure 4 below are lower than the real costs because of this underestimate. The prevention costs, which form part of the capital expenditure (Capex) for field development, generally, do not change within the short run business planning cycle of one year. The negative slope of the prevention cost curve in Figure 4 implies that employers and operators, who want to enhance the safety level by reducing the risk of an incident before the commencement of operations, need to invest more in safety over and above the statutory minimum standards.

An employer who starts with a higher level of prevention cost investment S_1 will have a higher safety level or a lower incident probability X_1 than a comparable employer who begins with a lower level of prevention cost investment S_2. In the long run, the negative slope of the prevention costs indicates positive marginal returns to the extent that more investment in safety from the capital expenditure perspective increases the safety level by reducing the probability of an incident occurring in subsequent years. At low-risk levels, the Prevention Cost curve becomes asymptotic to the vertical axis, indicating that the elimination of all risk is unlikely, even with significant increases in prevention expenditures (Brody *et al.*, 1990).

Figure 4: Perceived HSE Costs and Incident Probability



Source: Adapted from Brody *et al.* (1990)

The variable insurance costs (B) are a direct function of the risk level. The slope of the variable insurance costs with respect to the degree of risk is positive and greater than zero. This implies that the higher the risk of the employer, the greater the premiums they would be expected to pay to transfer that risk to the insurer. The total HSE cost curve (T), is given as the sum of the perceived accident costs (I_p) and the prevention costs (S). The total HSE costs, which are initially high for lower incident probability or the best safety level, begin to fall as incident probability increases via the introduction of risk. As the prevention costs fall and perceived accident costs rise, the total HSE cost curve also rises. The total HSE costs are minimised at the optimal cost C^* with the associated incident probability or risk threshold of X^*.

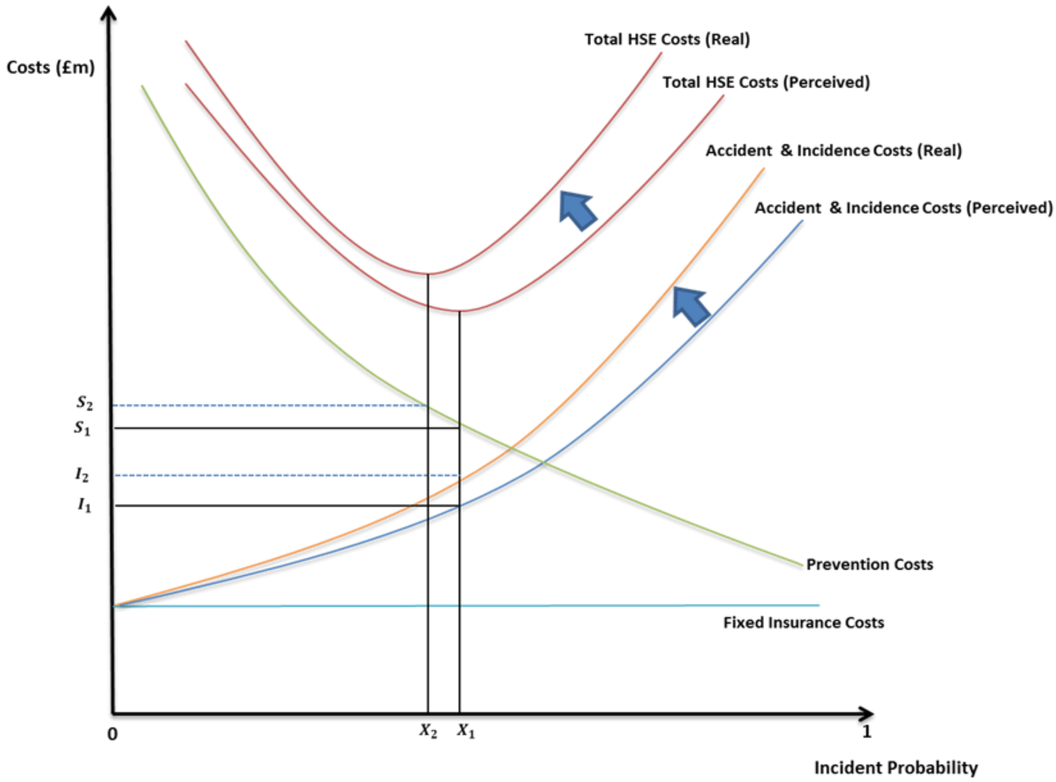
There exists an inverse relationship between prevention costs (S) and the accident and incidence costs (I_p). The higher the initial prevention costs resulting from the health, safety and environmental mitigation measures which must be incurred by the industry to prevent accidents before production, the lower the expected probability of an accident and the subsequent ex post-accident and incidence costs. Also, there exists a positive relationship between prevention costs and societal benefits regarding lower accidents, injuries and environmental spills or releases. More investment by the operator will reduce the expected accident probability, thus enhancing the overall societal welfare with the environment being preserved and less compensation given out to workers.

Factoring the indirect accident and incidence costs is depicted in **Error! Reference source not found.** below. The total HSE cost becomes the sum of the initial perceived accident costs (I_p) and the indirect costs. The industry, becoming aware, and estimating the indirect cost component, causes the total HSE and accident and incident cost curves to shift to the left due to the increased indirect cost factor (Brody *et al.*, 1990). The effect of the recognition or valuation of these indirect costs by the industry reduces the risk level to the new optimum threshold X_2^* compared to the original risk level X_1^*. Higher expenditure levels regarding prevention costs lead to reduced risk levels, whereas starting with a lower level of prevention expenditure has an associated increase in the risk level. This is also depicted by the negative slope of the prevention cost curve.

If the industry wants to mitigate the health, safety and environmental risk factors over the minimum regulatory risk threshold, they would have to incur higher total HSE investment costs. The industry would choose an optimal risk level at point X_2 relative to the total HSE cost curve as this corresponds to the point where the total prevention and real accident and incident costs are minimised.

Beyond this point, there is a disproportionate increase in the total HSE cost relative to a rise in the risk level. The cost to mitigate an extra unit of risk becomes disproportionate. This cost-minimizing goal of the industry on account of factoring in the indirect accident and incidence costs encourages firms to invest more in prevention ($S_2 > S_1$) concomitant with an enhanced safety level on account of a reduction in the incident probability ($X_2 < X_1$).

Figure 5: Total HSE Costs and Incident Probability



Source: Adapted from Brody *et al.* (1990)

The provision of an enhanced level of safety entails more capital expenditures in new technologies, processes and equipment. This implies that incremental costs increase to maintain the minimum safety standards set by the regulator. A central component of the operational risk management strategy of the industry should be an understanding of the costs of their investment decisions regarding improving workplace safety.

Gavious *et al.* (2009) note that most firms do not systematically evaluate or calculate these indirect costs. One reason adduced for this is the lack of knowledge and understanding by managers of compensation mechanisms involved in accidents, incidents and environmental releases. Most managers tend to believe that the costs are insured when they are not. This view is reinforced by Mossink and De Greef (2002) who argue that consequential accident and incident costs such as disruption to production, reputational damage, administrative and legal costs are often not known ex-ante by the employer. Despite this knowledge gap, the accident risk level or exposure of the employer often remains proportional to the economic repercussions they experience ex-post an incident.

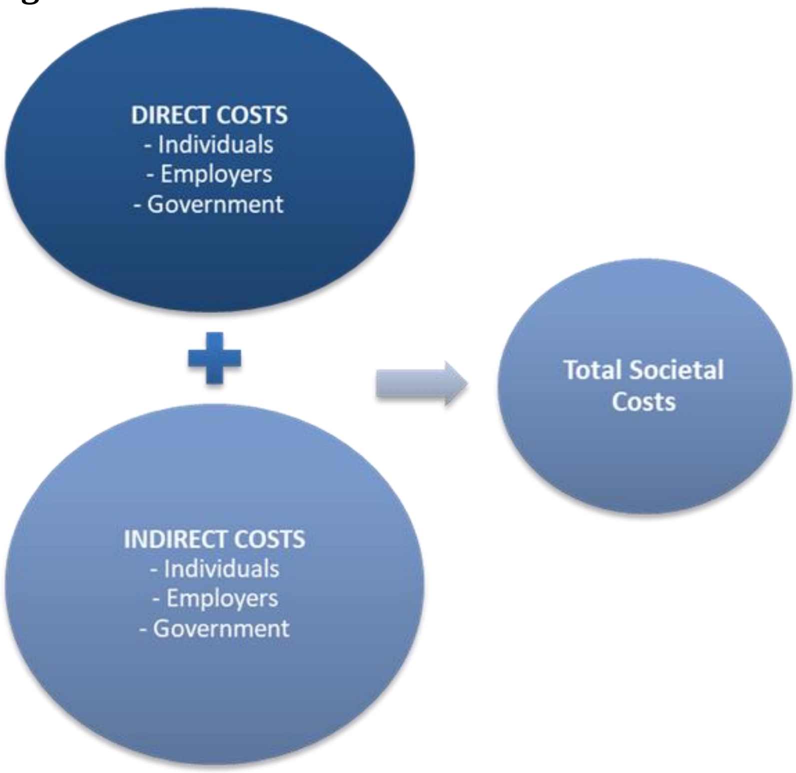
4 Impact of Health, Safety and Environment Costs in the offshore Oil and Gas Industry

The economic impact of the ex-post-accident and incidence costs (I) in the offshore oil and gas industry is further analysed within the direct and indirect cost framework, as shown in Figure 6. For many operators, the direct costs may be estimated and captured within their risk management models, but the challenge often arises with the estimation of the indirect costs (Hudson & Stephens, 2000). A broad consensus exists in the industry on the nature of these costs. However, the subject of debate often centres on the question of whether the removal of a hazard or risk dictated by the regulatory policy, *"so far as is practicable"*, requires an expensive engineering or an inexpensive administrative cost (Maxwell, 2004).

Under the Health and Safety Act 1974 and other national provisions, cost-benefit calculations form an important basis for the enforcement of safety rules. Even though the full costs of accidents and injuries are sometimes difficult to quantify in monetary terms, accidents create costs for operators[5] and subcontractors, individual workers and for society (Mossink & De-Greef, 2002). An appreciation of the total costs of offshore accidents, injuries, and environmental releases using the direct and indirect cost approach should thus determine the appropriate HSE measures.

[5] This includes Joint Venture (JV) partners operating a lease. The amount each partner bears for the HSE costs are often estimated based on their equity stake in the venture.

Figure 6: Breakdown of economic costs of accidents



Source: Adapted from Health and Safety Executive (2011)

Individuals

The direct costs represent monetary estimates of the net costs of accidents, injuries and environmental releases that individuals suffer and, in some cases, those who are close to them. The direct financial costs are calculated by estimating payments that must be made and lost personal income that comes about because of the injuries or effect of the environmental releases. These include loss of income, compensation payments, health and rehabilitation costs and administrative costs (Health and Safety Executive, 2011). In the United Kingdom, the average £62,500[6] salary earned by an offshore worker could be lost due to an incident in the absence of any compensation payments or benefits.

Compensation payments to individuals represent the lump sum payments made from claims against employers' liability (EL) insurance cover, which is the compulsory insurance for all employers other than the government (Health and Safety Executive, 2011). Individual costs also include incapacity payments or quality of life costs for the loss of health, pain and suffering. Health and rehabilitation costs represent medical expenses and travel costs to the

[6] Details available at https://www.cwjobs.co.uk/salary-checker/average-offshore-salary [Accessed 22 November 2019]

hospital made out-of-pocket by the individual offshore worker. The administrative costs encapsulate costs to the individual or their friends and family of the time spent initiating and managing claims for sick pay and state benefits, and compensation and insurance payouts (Health and Safety Executive, 2011). A trade-off arises where the loss of worker productivity from being incapacitated due to an injury has to be balanced with safety investments that reduce the probability of an accident, injury or environmental spill or release occurring.

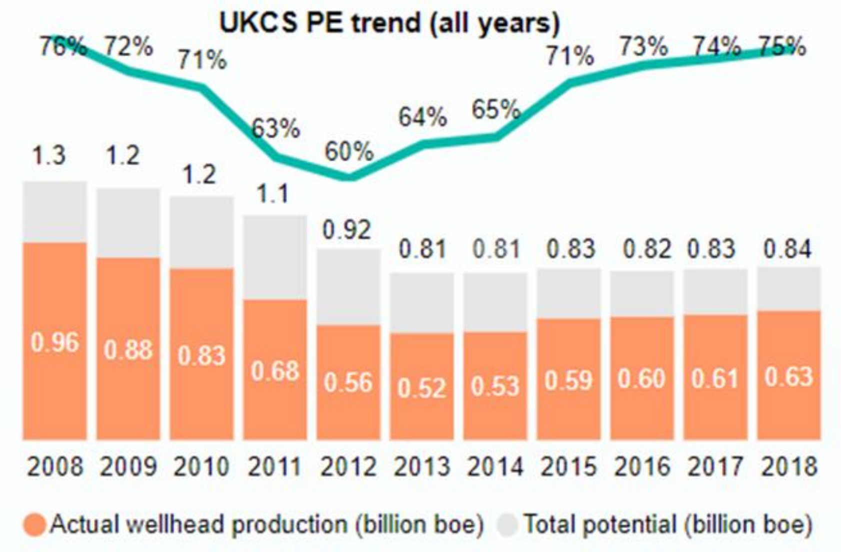
Employers

The direct costs to employers of workplace injury, accidents and environmental spills include sick pay payments, liabilities and fines, increased insurance premiums, production losses, and administrative and legal costs. Sick pay payments include payments made to the absent employee in addition to recruitment and training costs to replace the employee if short-run production output is to be maintained. In the absence of major injuries or accidents to the workforce, necessitating a complete shutdown of production systems, most offshore platforms and facilities would continue to work as usual by replacing the sick or injured worker with temporary or contract staff.

The production costs include losses accrued due to deferred production, replacement costs for damages or repair of machines, and opportunity costs in cancelled orders representing lost income for the company. The opportunity costs can be estimated as a percentage of the lost production value. Between 2011 and 2015, production from the UK oil and gas industry fell by about 30% primarily due to both planned and unplanned shutdowns in existing fields with several key hub platforms and pipelines being closed for extended periods following incidents (Oil and Gas UK, 2013a). For example, part of the 468-kilometre SEAL pipeline system that exports gas from the Elgin-Franklin and Shearwater development to the SEAL terminal in Bacton had to be shut at certain periods in 2013 because of the gas leak from the Elgin-Franklin field. These unplanned shutdowns can impose financial constraints for the industry in terms of deferred production losses, reduction in production efficiency and increases in operational expenditure. **Error! Reference source not found.** highlights the extent of these costs on production efficiency in the UK oil and gas industry.

Regarding indirect costs, liabilities alone may not create enough incentives for the industry to invest in safety. Even though liabilities, in theory, force firms to internalise the costs of accidents, injuries and spills by adopting cost-effective technological developments to minimize potential future claims, firms that do not have enough financial resources to pay liability claims may simply declare bankruptcy (Richardson *et al.*, 2011). Other indirect HSE costs to the employer include training and compensation of replacement workers (lost labour time) and repairs to damaged production equipment.

Figure 7: UK Oil and Gas Production Efficiency



Source: Oil and Gas Authority (2019)

The employer's indirect costs are often higher than the direct costs because the former cannot be fully insured from an economic perspective. The ratio between the insured and uninsured costs creates an "iceberg effect" where the indirect costs often outweigh the direct costs of an accident, incident or environmental spill. According to some industry estimates, average uninsured losses, which include lost production value, can go as high as twenty-seven times the amount paid in insurance premiums (OGP, 1996). Using this upper bound, it implies that for every £1 million insurance payout, the operator or employer must provide an extra £27 million for uninsured losses. These additional payments can only come from the company's earnings. In some circumstances where the company cannot provide for these extra payments, it may declare bankruptcy. The Piper Alpha accident, which resulted in one of the most extended pieces of litigation in British history, cost approximately £20 million in total legal fees and £110 million[7] in financial compensation paid by Occidental Petroleum, the operator of the platform, to the survivors and the families of the victims.

Government

The direct costs are those costs not borne directly by the affected individuals or their employers (Health and Safety Executive, 2011). For example, state payments of benefits to individuals who are not able to work because of injury or ill health comprise a loss of state earnings, deemed a cost. Income tax and National Insurance contributions by workers may decline due to injuries and ill health that have taken people out of the labour market. In the UK, National Insurance contributions on sick pay are partially offset by contributions reclaimed by businesses under the percentage threshold scheme.[8]

Indirectly, the loss of economic output at the societal level arising from an individual's absence from work due to a workplace injury or illness can be assumed equivalent to the lost gross earnings of the affected individuals (Health and Safety Executive, 2011). Assuming full economy-wide employment, the absence of a worker due to an injury results in a decline in the labour force, thus, creating losses to the broader economy. As Dorman (2000) argues, the availability of a labour market can be a strong influencing factor on who bears the societal cost. That is, an easy replacement of an injured offshore worker can be viewed as indicating that the private costs for the employer are limited in scope, as parts of these costs are shifted on to society.

5 Performance Analysis of Health, Safety and Environment Trends in the UKCS

Here, we analyse the HSE performance of the UK's offshore oil and gas industry in Piper Alpha period. Our objective here is to understand the trends in offshore injuries, accidents, incidents, spills and hydrocarbon releases using data from the Hydrocarbon Releases (HCR) system and other industry databases. The analysis is conducted using data plots and statistical tools such as moving averages.

[7] Details available at https://www.scribd.com/doc/310451122/Remembering-Piper-Alpha-the-Night-the-Sea-Caught-Fire-the-Scotsman-14-June-2008 [Accessed 24 November 2019]
[8] Details available at http://www.hmrc.gov.uk/helpsheets/e14.pdf [Accessed 20 December 2019]

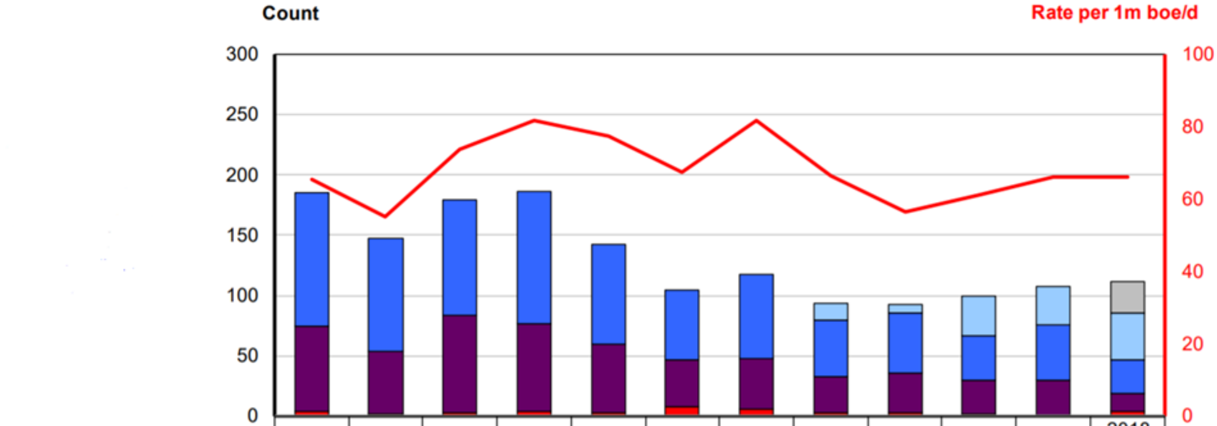
The HCR database contains supplementary information on all offshore releases of hydrocarbons reported to the Health and Safety Executive's Offshore Division (OSD) under the Reporting of Injuries, Diseases and Dangerous Occurrences (RIDDOR) Regulations 1995 and prior legislations. Primary data captured in the HCR database includes the installation name, incident date, location, process type, leak size, and severity of the incident. The Health and Safety Executive, together with industry, defines and uses a three-tier classification system of minor, significant, and major incidents for HCRs. The key focus for improving the United Kingdom's oil and gas industry HSE performance is centred on reducing the numbers and severity of accidents, incidents, injuries and fatalities as well as reducing environmental and hydrocarbon releases (HCRs). This has been accomplished through significant industry initiatives such as Step Change in Safety and new regulations such as by the European Union Offshore Safety Directive Regulator (OSDR).[9]

5.1 Hydrocarbon Releases Statistical Analysis

HCRs have reduced from 189 incidents in 2007/2008 to 96 incidents as of 2018, indicating a 100% reduction over the ten years as shown in Figure 8.[10] This is also in line with the HCR reduction target of 93.5 incidents by the end of March 2013, which was agreed to by the industry at the time. Nonetheless, the HCR rate as a proportion of the oil and gas produced has come down to 2007 levels at 66 releases per million barrels of oil equivalent/day (boe/d) production.

[9] https://www.hse.gov.uk/osdr/index.htm
[10] https://www.hse.gov.uk/offshore/statistics/hsr2018.pdf

Figure 8: Reported dangerous occurrences (offshore), 2007 – 2018



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018 p
Awaiting Classification	0	0	0	0	0	0	0	0	0	0	0	26
Non Process	0	0	0	0	0	0	0	14	7	33	32	39
Minor	110	93	95	109	82	58	70	47	50	37	46	28
Significant	71	52	81	73	57	39	42	30	33	28	29	15
Major	4	2	3	4	3	8	6	3	3	2	1	4
Release rate per 1m boe/d	66	55	74	82	78	67	82	66	56	61	66	66

Source: Health and Safety Executive (2018)

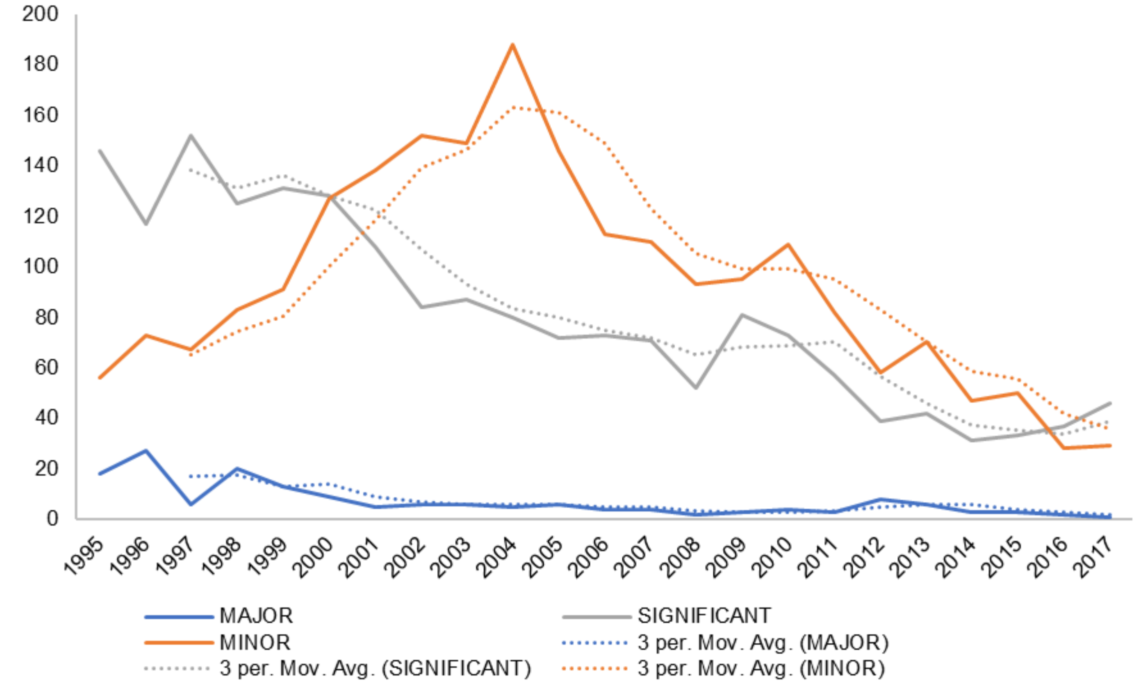
Also, as Figure 9 highlights, both major, minor and significant releases have been consistently declining on a year-on-year basis, although there was an increase in minor releases between 1998 to 2005. A comparative analysis of the trends in industry performance using a three-year moving average indicates that major releases have consistently fallen year-on-year from an average of 15 releases in 2000 to about six releases in the mid-2000s and currently about three major releases. Significant releases have also witnessed a considerable decline, averaging 140 releases recorded in the 1990s to 45 releases in post-2010.

One of the major factors driving the reduction in HCRs is the collaborative effort of the industry and other stakeholders working through forums such as Step Change in Safety, the United Kingdom's flagship offshore safety initiative. Step Change in Safety was set up in 1997 by industry trade associations to reduce the UK offshore industry injury rate by 50% and operated under the PILOT umbrella.[11] It now includes the Health and Safety Executive and Trade Unions within its broad consultative network which works with six steering groups to tackle priority health and safety issues. The six groups are organised in line with operational

[11] Details available at http://webarchive.nationalarchives.gov.uk/20101227132010/http:/www.pilottaskforce.co.uk [Accessed 03 January 2020]

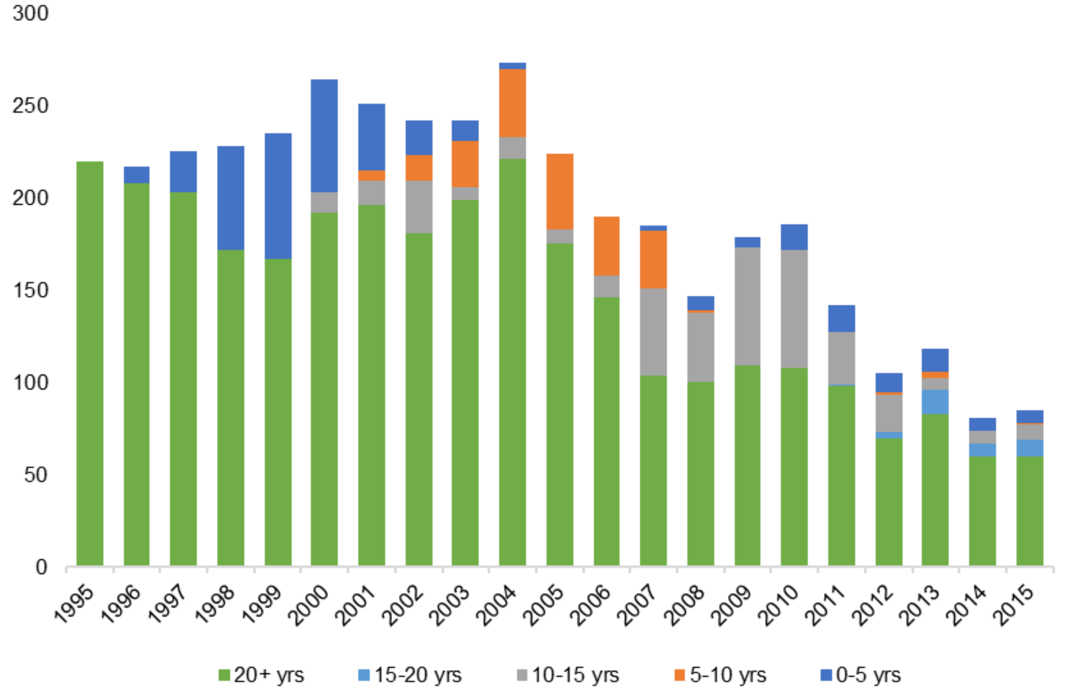
aspects of the industry, namely "asset integrity, competence, human factors, workforce engagement, helicopter safety, and marine transfer".[12]

Figure 9: HCRs by severity and moving averages, 1995-2017



Data Source: Health and Safety Executive (2020)

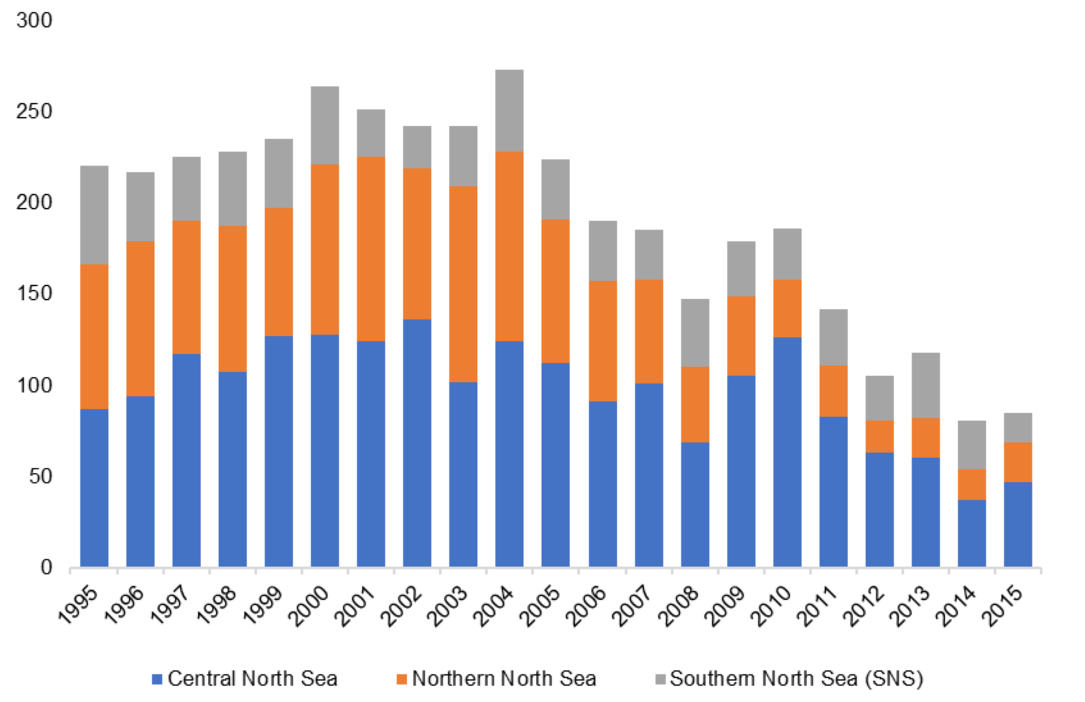
Figure 10: UKCS HCRs by facility age, 1995-2015



Data Source: Health and Safety Executive (2020)

[12] Details available at https://www.stepchangeinsafety.net/about-step-change-safety/steering-groups [Accessed 25 January 2020]

Figure 11: UKCS HCRs by location, 1995-2015



Data Source: Health and Safety Executive (2020)

Furthermore, as depicted in Figure 10, incidents of significant and major releases are related to the age of the facility. Given the many years of operations on older platforms, one would expect most of the HCRs to come from these older installations whereas newer ones with lower operational years are expected to have a lesser incidence of hydrocarbon releases, *ceteris paribus*. Here, age refers to the cumulative operational years of the installation at the time the discharge occurred. Some notable trends are observed from the data, namely decline, appreciation, and steady-state release frequencies. For example, HCRs from installations from releases from installations that are over 20 years of age dropped by 75% in 2015 compared to 1993 levels. Also, releases in the 15 to the 20-year category have witnessed little change over the past twenty years while HCRs in facilities less than five years old, rose significantly in the 1990s but massively declined from 2003/04 onwards.

Regarding the location of the facilities, the Central North Sea (CNS) recorded the significant majority with 2,306 releases representing 49.9% of total HCRs – figure 11. This is followed by the Northern North Sea (NNS) with 1,499 releases (32.5%) and finally the Southern North Sea (SNS) with 811 releases (17.6%). A closer analysis using five-year moving averages shows the improvements the industry has made in reducing HCRs. Releases from the Central North Sea region exhibited the greatest dispersion over time.

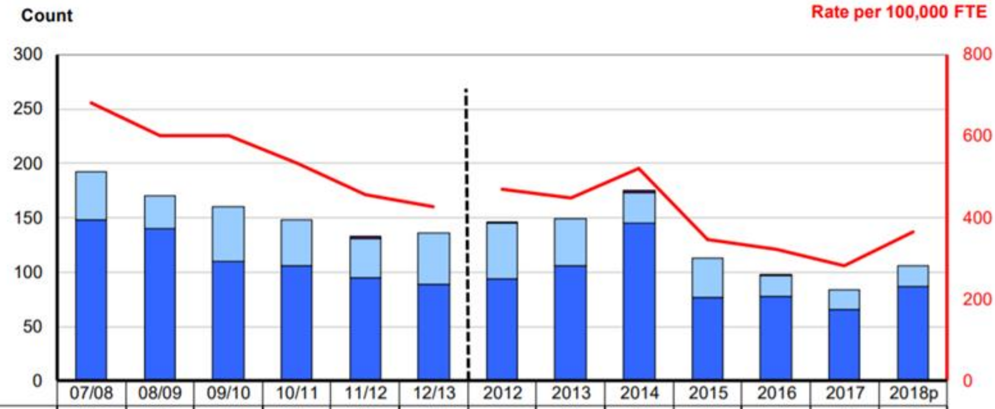
5.2 Offshore Incidents and Injury Statistical Analysis

Regarding offshore incidents and injury statistics (excluding helicopters), the combined injury rate in 2018 fell to 365 per 100,000 full-time equivalent (FTE) workers, compared to 682 per 100,000 FTE in 2007/2008. Figure 12 below illustrates the injury rate trends in the industry. Also, amongst the nine major industrial sectors, the oil and gas industry's safety performance has consistently been ranked among some of the best performance. In 2013, the sector recorded 530 non-fatal injuries per 100,000 workers based on a three-year moving average from 2009-2012 (Oil and Gas UK, 2013b).

Nonetheless, three fatalities since 2012 and six in the last ten years in the UKCS serve as an ongoing reminder of the hazards and risks involved in offshore oil and gas activities and the need to improve safety performance consistently.[13] Overall, injuries have been declining since 2007 with total injuries comprising fatalities, major, and over-3-day injuries have falling by 45% from 192 injuries recorded in 2007 to 106 in 2018 (Figures 12 and 13). The highest contributor to the decline has been the reduction in over-3-day injuries – that is, major injuries have decreased marginally compared to over-3-day injuries. Even though the over-3-day injuries constitute the major component of offshore injuries, a gradual reduction of the gap between the over-3-injuries and the fatalities and major injuries is observed from 2007 to 2018.

[13] https://www.hse.gov.uk/offshore/statistics/hsr2018.pdf. pg. 5

Figure 12: Reported Offshore Injuries, 2007 – 2018



	07/08	08/09	09/10	10/11	11/12	12/13	2012	2013	2014	2015	2016	2017	2018p
Fatal	0	0	0	0	2	0	1	0	2	0	1	0	0
Major/Specified	44	30	50	42	36	47	51	43	28	36	19	18	19
Over-3-day/Over-7-day	148	140	110	106	95	89	94	106	145	77	78	66	87
Rate per 100,000 FTE	682	602	602	535	458	428	469	447	521	346	323	282	365

Note: - - - Series break (change from fiscal year to calendar year)

Source: Health and Safety Executive (2018)

Table 1: Fatal Injuries Offshore

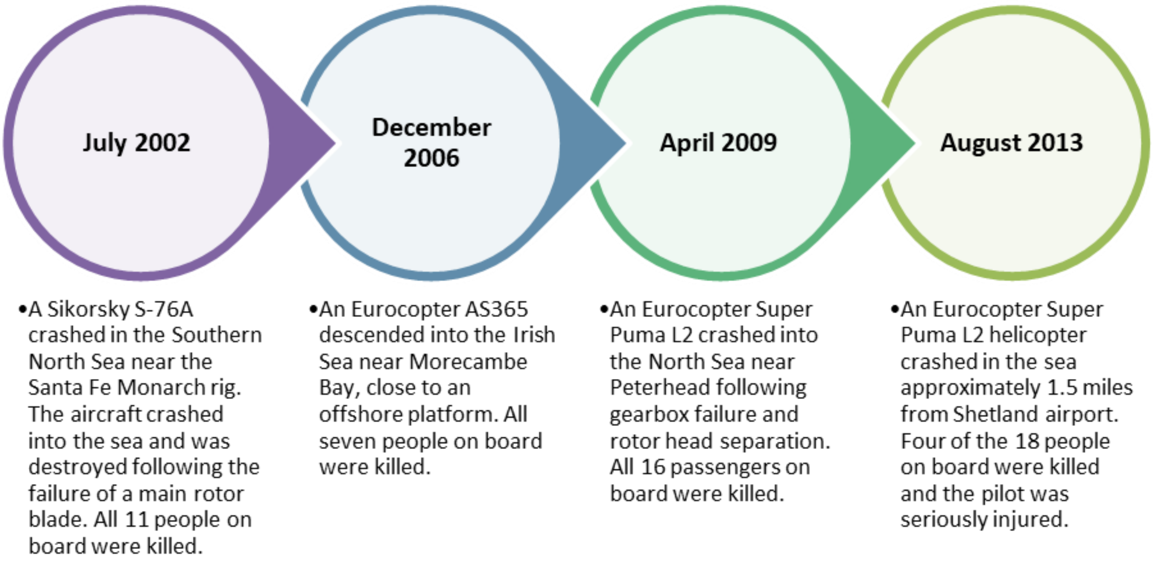
Year	Number of Fatalities	Year	Number of Fatalities
1996–97	2	2007–08	0
1997–98	3	2008–09	0
1998–99	1	2009–10	0
1999–00	2	2010–11	0
2000–01	3	2011–12	2
2001–02	3	2012–13	0
2002–03	0	2013–14	2
2003–04	3	2015	0
2004–05	0	2016	1
2005–06	2	2017	0
2006–07	2	2018	0

Source: Oil and gas UK, 2018

Regarding offshore helicopter safety, statistics from 1997 to 2018 indicate there have been four fatal accidents, which have claimed the lives of 38 offshore workers and flight crew (see Figure 13) and there have been 18 non-fatal accidents.[14] The major causes of these accidents include major component failures, pilot error (human factors), lightning strikes, major airframe damage, and main and tail rotor damage (Oil and Gas UK, 2018).

[14] Details available at https://oilandgasuk.co.uk/wp-content/uploads/2019/10/Health-and-Safety-Report-2019.pdf

Figure 13: Fatal North Sea Helicopter Crashes



Source: Oil and Gas UK (2019)

In the UK, the responsibility for offshore helicopter safety lies with the Civil Aviation Authority (CAA) and the Health and Safety Executive (HSE). The Civil Aviation Authority regulates helicopter operators concerning activities at onshore heliports and when a helicopter is in UK airspace; the Health and Safety Executive (HSE) regulates the owners and operators of offshore installations concerning personnel health and safety risks from the time they touchdown on an offshore installation to their departure.[15]

Helicopter operators holding an Air Operator's Certificate (AOC) must satisfy the CAA that the safety for publicly transporting passengers has been met. This includes safety briefing of passengers as well as the provision of personal safety equipment aboard the aircraft carried out in conjunction with offshore duty holders.[16] The responsibility for the safety of the installation, which includes the structural integrity of the helideck and helideck operations lies with the operators. A Memorandum of Understanding exists between the CAA and HSE, which ensures effective coordination between the two bodies in delivering on the ultimate objective of optimizing offshore safety.

[15] Details available at http://www.hse.gov.uk/research/otopdf/2000/oto00089.pdf
[16] Details available at http://www.hse.gov.uk/pubns/indg219.pdf

5.3 Produced Water Handling and Environmental Statistical Analysis

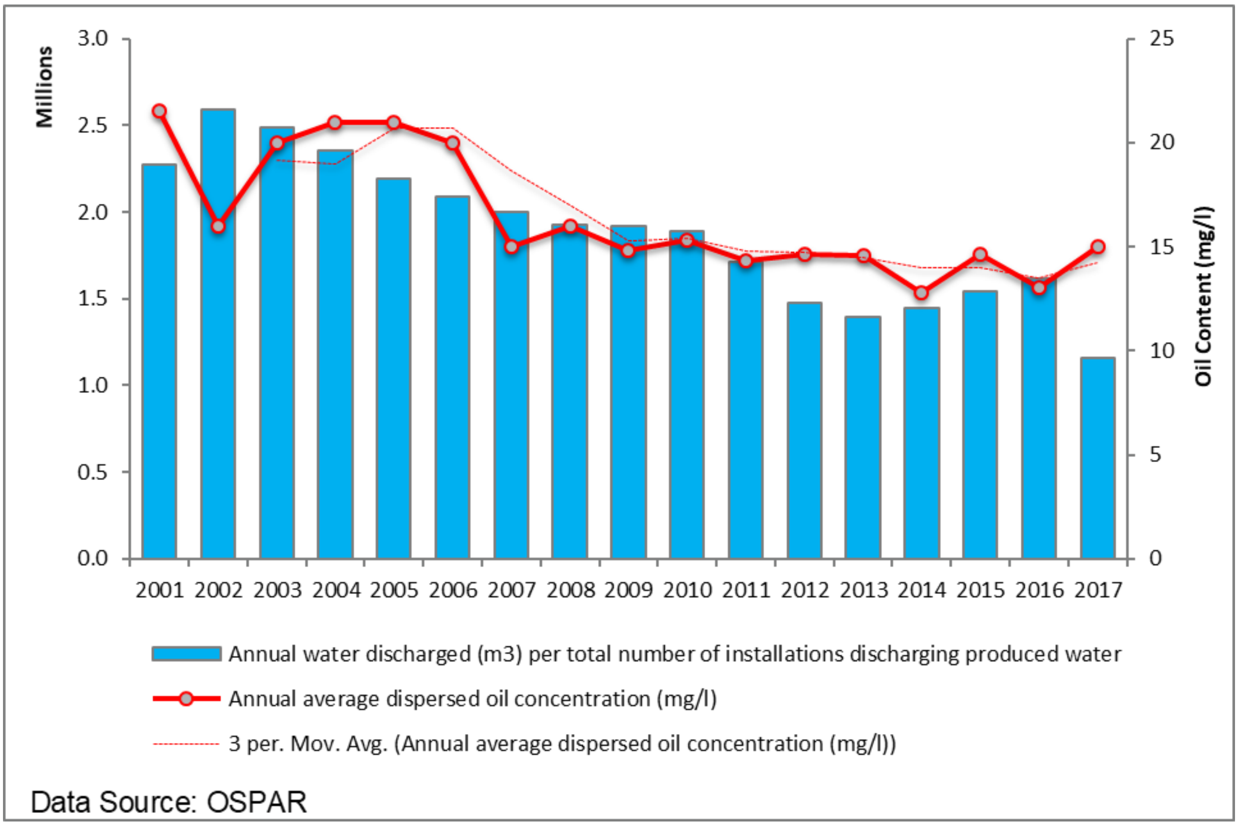
Hydrocarbons come mixed with water within the reservoirs in their natural state, and during the extraction process. The water is separated from the oil and gas in the first stage of processing.[17] The oil and gas are exported while the produced water is disposed of by discharging into the sea after treatment to meet regulatory limits. Naturally occurring dispersed oil and radioactive materials, dissolved organic compounds, including aromatic hydrocarbons and organic acids, among others added during the separation process, make up the complex chemistry of produced water. As an inextricable part of the recovery and separation processes for hydrocarbons, produced water is by far the largest waste stream by volume (Society of Petroleum Engineers, 2020; Danforth et al., 2019). In addition to formation water, produced water includes condensation water and reproduced injection water as well as water used for desalting oil (Society of Petroleum Engineers, 2020). The amounts of produced water and concentrations of the contaminants vary over the life cycle of the reservoir and on a field-by-field basis depending on the formation chemistry, rock-fluid interactions and the type of production taking place (Bakke, 2013).

In the UKCS, the number of installations discharging oil in produced water has increased marginally from 112 to 123 (averaging 105 installations) between 2001 and 2017 according to OSPAR statistics. Standardising the amount of produced water discharges by the number of facilities and further segmentation using geographical as well as age characteristics of the installations provides a better understanding of the statistical trends. Using a three-year moving average to capture seasonality in the data, Figure 14 shows the gradual and sustained decline in produced water releases, reflecting the efforts made by industry and regulator in adopting new standards and directives. Increasingly, environmental regulations on produced water have become more stringent, requiring extensive treatment before discharge (Society of Petroleum Engineers, 2020). This treatment and disposal have cost implications in respect of the volumes produced and technologies utilised. Some estimates put global industry treatment costs for produced water at more than $40 billion annually (Society of Petroleum Engineers, 2020). Though OSPAR and subsequent OPPC Regulations advise operators to adopt best

[17] Details available at https://oilandgasuk.co.uk/wp-content/uploads/2019/08/Environment-Report-2019-AUG20.pdf [Accessed 24 February 2020]

available techniques and environmental practices on produced water management, the costs and space needed for the deployment of these technologies as well as the weight limitations on offshore installations need to be juxtaposed against the environmental benefit which in turn needs to be accurately assessed.

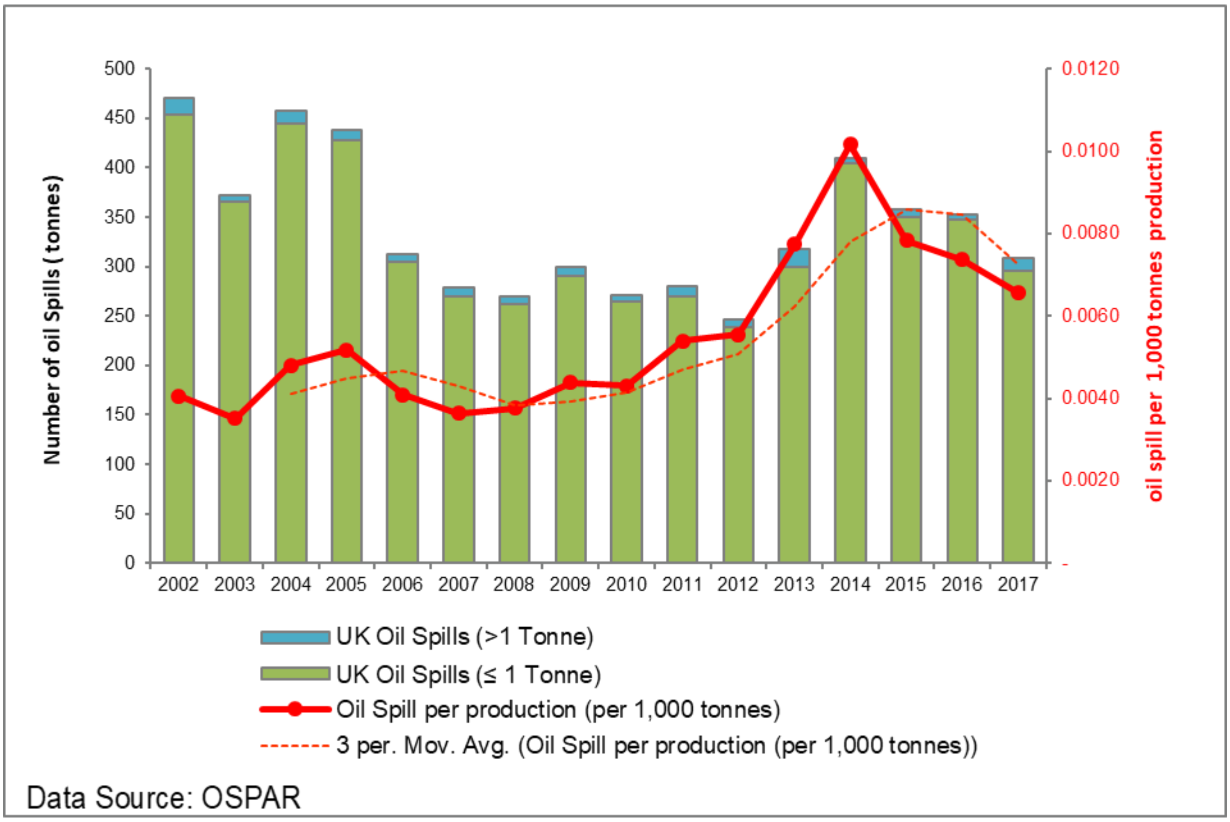
Figure 14: Annual water discharged (m3) per total number of installations discharging produced water



Also, **Error! Reference source not found.** Figure 15 provides a detailed breakdown of oil spills in the UKCS from 2002 to 2017. The amount of oil spilled has declined during the period under consideration after peaking at 470 spills in 2002 compared to 309 spill incidents in 2017. There has been an average of 340 spill incidents per year over the period. Regarding long-term trends, a three-year moving average of the frequency of oil spill incidents per 1,000 tonnes of hydrocarbon production in the UKCS shows that spills have increased by 62% compared to 2002 baseline levels. This is in part driven by several recent unplanned shutdowns (2015-2015) and consequent reductions in production efficiency.

To ensure that the risk of oil pollution is reduced to a minimum in line with the ALARP - as low as reasonably practicable- principle, the oil and gas industry, together with the government, has taken initiatives to ensure that in the event of a full-blown accident and resultant oil spill, adequate financial provisions are provided to cater for clean-up and other third-party costs. The Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations[18] 2005 (OPPC Regulations) and Amendment Regulations 2011 which regulate the emission of oil from offshore installations, was designed in line with the recommended standards agreed under the OSPAR 2002 protocols. The 2005 Regulations were amended in 2011 to extend to the discharge of oil in offshore gas storage and unloading activities and carbon dioxide storage operations.[19]

Figure 15: UKCS Oil Spill Statistics



The regulations now categorise what is permissible by clearly distinguishing unlawful releases of oil from discharges from those that may be lawful if made by the terms and conditions of a permit.[20] Also, the regulations amend the definition of 'offshore installation' by extending it to encompass all pipelines. Operators are required to have a permit to discharge oil and

[18] An amendment regulation was made in 2011 to provide a narrower focus to the law to clearly distinguish unlawful releases of oil from discharges, which may be lawful if made in agreement with the terms and conditions of a permit
[19] Details available at http://www.legislation.gov.uk/uksi/2011/983/note/made and https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/62694/oppc-consolidated.pdf [Accessed 17 February 2020]
[20] Under the regulations, "discharge", in relation to oil, means its release from an offshore installation; "emission" means the direct or indirect release of substances from an individual or diffuse source into the air or into relevant waters. ibid at 2

produced water. The legislation explicitly states that no oil shall be discharged except by the terms and conditions attached to a permit granted by the Secretary of State.[21]

Furthermore, on the issuance of a permit to an operator, conditions may be assigned by the Secretary of State to ensure that appropriate restrictions and safeguards are incorporated to protect the environment.[22] These include measures to ensure that: "the concentration, frequency, quantity, location or duration of any discharge is subject to appropriate restrictions; appropriate measures are taken to minimise pollution including, in particular, the appropriate use of technology to limit discharges; necessary measures are taken to prevent incidents affecting the environment or, where they occur, to limit their consequences in relation to the environment".[23]

Holding the necessary permit absolves permit holders or operators from criminal liability from spilling dispersed oil into the sea so long as the provisions are followed. Should a permit holder or operator not have enough allowances to cover its discharges, they are liable to pay a fine usually calculated on a per-unit basis of the discharged oil. The permit does not preclude civil liability proceedings from being brought by the public or the authorities for damage caused (Budiman, 2011).

Likewise, the Offshore Pollution Liability (OPOL) framework and agreement, which has been in existence since the early days of oil and gas exploration and production in the UKCS, requires operating companies to accept strict liability for pollution damage by providing mutual guarantees which members bear for each other's obligations.[24] The agreement applies to all offshore facilities from which there is a risk of a discharge of oil which could cause pollution damage. The operators are required to demonstrate financial responsibility for costs that result from the remediation of an oil spill as well as third party compensation for pollution damage, up to a certain limit (Oil and Gas UK, 2012). OPOL has been accepted to represent

[21] ibid at 5.1
[22] Section 2 of the Regulations
[23] ibid 2(a)(b)(c)(d)
[24] Details available at http://www.legislation.gov.uk/uksi/1988/1213/schedule/4/paragraph/23/made [Accessed 21 February 2020]

the active response of the oil and gas industry to dealing with compensation claims arising from offshore oil pollution incidents. In the intervening years, OPOL liability limits have been increased to US$250 million for any one incident and US$500 million annual aggregate for operators which are part of the same group of companies (OPOL, 2019).

All these initiatives have collectively contributed to improving the safety performance of the UK's offshore oil and gas industry.

6 Conclusions

The effective management of HSE remains a priority for operators, government regulators, employers and civil society groups. Recent events have brought to the fore the interrelationship between health, safety and environmental management and the effect on the financial performance and productivity of the industry. Health, Safety and Environmental considerations will play an integral role in maximising the ultimate recovery of the remaining oil and gas reserves in the UKCS and the world at large. The national policy objective of maximising the economic recovery of oil and gas reserves in a mature basin such as the UKCS will need to be anchored not just on incentivised field economics and fiscal measures, but on a greater understanding of the inherent HSE risks in offshore operations and their economic implications for the industry.

HSE compliance is an important component of any industry and more so in the offshore oil and gas industry, where the inherent risks associated with operating in difficult subsurface and topsides conditions are high. Workplace accidents, injuries and environmental releases in the offshore oil and gas industry impose economic costs on operators, employers and the wider society. It is also the case that most of these costs are sometimes external to the operators and employers. To this extent, there is then the need to benchmark HSE costs within a well-defined analytical framework, which details the relevant industry cost drivers and expenditure patterns. This must be anchored on a regulatory framework in which all industry players – and not just operators and duty holders – proactively play a role towards an understanding of latent offshore risks as well as influencing and controlling offshore working conditions.

As the UK offshore industry health and safety regulator notes in their recent strategy document, *"preventing major accidents requires the maintenance of production facilities and the sub-sea pipeline network…. In this way, achievement of good health and safety standards will reduce the risk of major pollution incidents and contribute to securing the energy resilience of the UK, as well as protect workers"*. In an era of dwindling field sizes and complex geological characteristics such as high pressure and temperature (HPHT) fields in ever-deeper waters, the challenges of ensuring increased production uptimes and the achievement of good health and safety standards requires that HSE risks and associated life cycle costs to society — namely the initial Prevention Costs (S), and the Accident and Incidence Costs (I) — are fully understood. To achieve this, investments in new production assets, as well as the extension of the life of existing ones, need to be anchored on improved cooperation and information sharing between industry participants and the regulator through initiatives such as asset stewardship, infrastructure and technology strategies in line with the Wood Review (2014) recommendations.

In contextualising HSE issues, we propose an economic approach in which the industry should not perceive HSE compliance as costly in terms of the time and effort it takes to identify risks and put in place the necessary mitigating strategies. Instead, the approach should be seen from the perspective making the right HSE investments can benefit the operator and society. This requires appropriate framework to assess the probability of incident occurrences as well as the necessary contingency and mitigation plans.

The standard cost-benefit approach provides a reasonable basis for evaluating HSE investment and regulatory decisions and remains important from a public policy perspective in terms of the provision of public goods. We propose the adoption and application of more risk-based concepts to addressing offshore HSE issues that allow the estimation of what the optimal levels of risk should be within the regulatory environment using measures such as society's collective Willingness-to-Pay (WTP) and Willingness- to-Accept (WTA). A sound cost-benefit analysis framework that has an accurate estimate of the costs and benefits, can be utilized to justify the need for investing in health, safety and the environment in terms of the returns to the employer, employees and the society by lowering the expected social costs and externalities.

The analysis of HSE data from the UKCS from 1995 to 2018 indicates improved offshore safety performance levels. These outcomes are primarily due to the various reform programmes embarked upon following the Piper Alpha accident such as the enhanced regulatory focus, introduction of 'safety cases'[25], and increased capital investments in facilities by operators and others. Despite this, significant risks persist in offshore oil and gas operations where low-probability-high-impact incidents can cause considerable loss of life and destruction of the environment and property.

Concerning hydrocarbon releases, we find that major and significant releases have been on the decline on a year-on-year basis. In contrast, minor releases continue to exhibit higher volatility. HCRs have reduced from 189 incidents in 2007/2008 to 96 incidents as at 2018, indicating a 100% reduction over the ten-year period. To consolidate these gains, many oil and gas operators in the UKCS have developed and implemented individual hydrocarbon release reduction plans that are widely shared across the industry. Other industry statistics show that the UKCS has witnessed a steady decline in non-fatal, over-three-day, and combined fatal and major injury rates. The collective fatal accident rate of 0.52 per 100 million hours worked, places the region as one of the safest in the industry globally.

Finally, in the aftermath of the Deepwater Horizon incident and on the advice of the Oil Spill Prevention and Response Advisory Group (OSPRAG), operators are now required to demonstrate financial responsibility for costs that result from the remediation of an oil spill as well as third party compensation for pollution damage. The Offshore Pollution Liability Association (OPOL) represents the active response of the industry in dealing with compensation claims arising from offshore oil pollution incidents. Applicants to the common compensation scheme are required to provide evidence of financial capability to fulfil obligations under Clause IV of the OPOL Agreement. The maximum OPOL limit per incident has been increased to ensure adequate cover.

[25] See Health and Safety Executive, 2006. A guide to the Offshore Installations (Safety Case) Regulations 2005.

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