Health, safety and environmental (HSE) regulation and outcomes in the offshore oil and gas industry: Performance review of trends in the United Kingdom Continental Shelf

Theophilus Acheampong[∂]*, **Alexander G. Kemp**[∂]

Abstract:

This paper contributes to understanding health, safety and environmental (HSE) regulation and performance in the offshore oil and gas industry. The United Kingdom Continental Shelf (UKCS) is used to explain how both safety investments by oil companies and regulatory initiatives can collectively contribute to enhancing standards, thereby reducing total accident and incident costs. We apply theoretical and analytical dimensions: firstly, by characterising an economic approach for evaluating HSE investments, and secondly, undertaking comparative statistical analysis of UKCS safety performance. Our findings indicate that the cost-benefit approach has been beneficial for evaluating HSE investment decisions to meet stricter regulatory compliance standards. Regarding the comparative analysis, we find that there has been a considerable improvement in safety in the UKCS over the past two decades, indicated by declining hydrocarbon releases (safety indicator) and declining injury rates (health indicator). Nonetheless, while produced water discharges (environment indicator) have also declined, the data also shows that the frequency of oil spill incidents have increased by 62% compared to 2002 baseline levels. This is partly explained by several recent unplanned shutdowns, especially between 2013 and 2016, and consequent reductions in production efficiency due to ageing infrastructure. Overall, the findings suggest that fair, effective, and participatory regulatory regimes can ensure a collective drive by all stakeholders towards improving industry safety performance and promote a better safety environment.

Keywords: Health; safety; environment; accidents; hydrocarbon releases; cost-benefit analysis

1 Introduction

Health, Safety and Environment (HSE) compliance is an essential component of any industry more so in the offshore oil and gas industry where there are high inherent risks. 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 is 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 US$65 billion (Bousso, 2018).

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

[∂] Department of Economics & Aberdeen Centre for Research in Energy Economics and Finance (ACREEF), University of Aberdeen, United Kingdom. Email: theophilus.acheampong@abdn.ac.uk
[∂] Department of Economics & Aberdeen Centre for Research in Energy Economics and Finance (ACREEF), University of Aberdeen, United Kingdom. Email: a.g.kemp@abdn.ac.uk

or better the current standards. Furthermore, market events such as the 2014-2017 and 2020 oil price slump add to these concerns on whether enough is being done by the industry to improve safety further or whether market dynamics necessitate cutting back on investments in enhancing safety performance

Given the foregoing issues of drilling for oil and gas in frontier regions, low oil prices and ever-increasing regulatory demands, it becomes essential 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. 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 which minimises total HSE costs – the cost-benefit analysis (CBA) or CBA framework (Hopkins, 2015; Paltrinieri, 2012).

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 production from the United Kingdom Continental Shelf (UKCS) accounts for over 50% of this demand (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 reviewing HSE policy and the performance of the offshore oil and gas industry. We use the UKCS as one of the best practice exemplars on 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 dimensions: firstly, by characterising an economic approach for evaluating HSE investments, and secondly, undertaking a comparative statistical analysis of some of the major industry performance trends. The extrapolation of some representative cases, systems or accidents is done to show how the CBA principles, which have been applied via channels such as the safety case regime in the UKCS, have led to improvements in core HSE performance indicators.

The rest of the paper is structured as follows: Section 2 describes the economics of health and safety in an offshore oil and gas context as well as discussing some of the principles for evaluating HSE investment. A breakdown of the economic costs of accidents is also discussed here. In Section 3, we conduct performance analysis of HSE outcomes in the United Kingdom's offshore oil and gas industry using various data plots and statistical trend analysis tools such as moving averages. Primary performance indicators of importance here are hydrocarbon leaks or releases (safety proxy), incidents and injuries (health proxy), and produced water discharges and oil spills (environment proxy). The analysis then goes further to explain the extent to which various investments and government-industry initiatives have contributed to improving the industry's HSE performance outcomes. We then conclude in Section 4.

2 Review of economic approaches for evaluating HSE investments

We start off with a framework to guide our understanding of why governments choose to regulate and enforce HSE standards.[1] HSE compliance should be seen from the perspective that making the right HSE investments can benefit the operator and society by having in place an assessment

[1] The model and subsequent analysis we present in this section closely follows the works of Curington (1986) and Auld et al. (2001).

of the probability of an incident occurring. Working in an offshore oil and gas environment is inherently risk. However, the actions of agents, be they employers or workers can affect this safety level. Hence, to control for the actions of these agents to ensure optimal safety, based on a baseline accident or injury probability, the government regulator, introduces a policy or legislative induced measure such as regulations to force these agents to comply.

Conceptually, consider an offshore installation operating in the UKCS: for this installation, let π be the probability that an accident occurs which causes injuries and stops employees from working work. Following Auld *et al.* (2001), the probability that an accident occurs can be conceived of as a function of some unalterable risk (χ_u), alterable risk (χ_a) and general economic conditions (G_e) prevalent in the industry, such as changes in macroeconomy – for example, oil prices. The unalterable risk, which is latent, is assumed to be independent of firm and government efforts and thus remains a characteristic defining the inherent baseline hazards in the industry (Auld *et al.*, 2001). In contrast, the alterable risk can be influenced by both operators and through government action such as imposing HSE standards and investments on injury prevention (Auld *et al.*, 2001; Curington, 1986). We define the probability of an accident related to χ_u,χ_a and G_e as well as the quantity of safety inputs (S) and labour (L) as

$$\pi = f(\chi_a, \chi_u, G_e) = f(S, L) \text{ and } {}^{d\pi}/_{dS} < 0, {}^{d\pi}/_{dL} > 0 \qquad [2.1]$$

Because accidents impose costs on firms due to the loss of lives and damage to physical capital, operators can reduce the accident probability by incurring expenditures or investing on injury prevention namely in safety equipment and infrastructure (Song and Mu, 2013). We conceive of this as the result of their effort to minimise the sum of injury costs and injury prevention costs (Curington, 1986). In line with Curington (1986), we conceive an offshore operator's accident costs C_a as the aggregate of an observed risk-related wage differential (w) as well as other non-wage injury costs (F), summed over all labour input (L) and this increases with the accident probability:

$$C_a = [F\pi + w(\pi)]L \text{ where } {}^{dw}/_{d\pi} > 0 \qquad [2.2]$$

An operator reduces the alterable risk by investing in safety capital Φ_{sc} at costs $C(\Phi_{sc})$, which is a function of the safety inputs (Song and Mu, 2013). The accident prevention expenditures $C(\Phi_{sc})$ can be related to the operating firm's accident prevention cost function using an inverse accident-risk function defined as $C(\Phi_{sc})S = C(\Phi_{sc}).Z(\pi, L)$. Accidents on an offshore installation cause output to diminish and disruption to production from other interconnected hubs and facilities. Thus, closely following Auld *et al.* (2001), we define the expected marginal revenue loss to the operator $R = C_a = [F\pi + w(\pi)]L$ – that is, the firm's accident costs comprising the risk-related wage premiums and non-wage costs - due to a workplace accident can be defined as

$$\pi R = R.f(\chi_a, \chi_u, G_e) = C_a = \pi[F\pi + w(\pi)]L \qquad [2.3]$$

Here, the operating firm will use additional safety inputs (S) to reduce the accident rate π until the operator's accident costs C_a and injury prevention expenditures $C(\Phi_{sc})$ are minimised. The first order conditions with respect to safety inputs is given as:

$$Min\ C_a + C(\Phi_{sc})S = [F\pi + w(\pi)]L + C(\Phi_{sc}).Z(\pi, L) \qquad [2.4]$$

$$\frac{dQ}{dS} = \left[F\frac{d\pi}{dS} + \frac{dw}{d\pi}\frac{d\pi}{dS}\right] + C(\Phi_{sc})\frac{dZ}{d\pi}\frac{d\pi}{dS} = 0 \qquad [2.5]$$

$$\left[F + \frac{dw}{d\pi}\right]L = -C(\Phi_{sc})\frac{dZ}{d\pi} \qquad [2.6]$$

A risk-neutral firm's incentive for its profit-maximising choice of safety capital Φ_{sc}^* is given by equating the per unit marginal cost of acquiring safety capital to prevent accidents $-C(\Phi_{sc})\frac{dZ}{d\pi}$ to the marginal benefit of the reduced wage premiums and reduced non-wage costs $\left[F + \frac{dw}{d\pi}\right]L$.

This can also be represented as:

$$\frac{dC(\Phi_{sc})}{d\Phi_{sc}^{*}} = \frac{dR.f(\chi_a, \chi_u, G_e)}{d\Phi_{sc}^{*}} = \frac{d\pi[F\pi + w(\pi)]L}{d\Phi_{sc}^{*}} \quad [2.7]$$

2.1 Characterising the Market Failure

Though the operating firm's investment in safety capital decreases the alterable risk from χ_a to χ_a', the regulator is faced with the challenge of determining whether this risk distribution is socially optimal given information asymmetry as well as the divergence of firm and government objectives (Auld *et al.*, 2001).[2] The regulator can mandate minimum safety standards Φ_g together with sanctions for non-compliance as well as other market-based economic incentives such as experience ratings for companies operating in the industry to make additional investments in safety and thereby reduce the alterable risk (Filer and Golbe, 2003; Hedlund, 2000; Feng *et al.*, 2014). The minimum threshold for the safety capital, which satisfies the social cost objective can be defined as:

$$Regulators\ safety\ objective{:}\ \Phi_g \geq \Phi_{sc}^{*} \quad [2.8]$$

That is, firms will be liable to fines if they are found to have underinvested in safety capital so long as the all-encompassing regulatory safety capital mandate Φ_g remains above the private safety capital Φ_{sc}^{*} of the operating firm.

However, we consider that regulatory monitoring is expensive and imperfect due to resource constraints, among others. So the trade-off for a firm would be to calculate the safety capital differential $C(\Phi_g) - C(\Phi_{sc}^{*})$ weighted by the probability of being inspected and caught for violating the safety standards ρ_k for which they pay a fine or are convicted in the law courts K.[3] This trade-off is given as

$$Firms\ Tradeoff\ Decision{:}\ C(\Phi_g) - C(\Phi_{sc}^{*}) \geq \rho_k K \quad [2.9]$$

From the above, firms or even industries with a high degree of alterable risk χ_a' which consequently affects the probability of an accident will benefit from safety regulations and standards through schemes such as the Safety Case regulations which control major accident hazards as well as regular inspections and audits (Viscussi, 1979; Curington, 1986; Auld *et al.*, 2001). To that extent, the regulatory policy is considered as producing capital costs in terms of health and safety investments, which then influence safety levels and by extension, the overall industry. The optimal safety perspective, which includes the operator's optimal investment in safety based on a standard model of profit maximisation, and this would occur at the point where the marginal benefits equal the marginal costs. 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* an offshore accident or incident, operators react by spending more on prevention costs to reduce the probability of future accidents. Higher investment in expenditures on safety and training, in turn, increases the marginal returns to prevention.

The equilibrium level of safety is determined by the relationship between the operating firm's willingness-to-pay (WTP) for safety through the provision of safety inputs to the production process and society's collective willingness-to-accept (WTA) the risks posed by offshore oil and gas operations (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

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[2] Firm's objective is normally centred on a much narrow construct of minimising loss of profits (private costs) due to an accident whereas government or regulator's objective is typically more encompassing to include all potential social costs. See Viscussi (1979) and Auld *et al.* (2001).

[3] Similar arguments advanced by Song and Mu (2013).

associated with health, safety and the environment should be defined and estimated for use in the offshore oil and gas context. Despite its public goods attribute, the value that society places on HSE can sometimes not be readily measured as that is often subjective. Significant disparities can exist between society's WTP for a small increase in their allocation of HSE benefits and the corresponding WTA a reduction of the same magnitude (Kniesner and Viscussi, 2019; Guria et al., 2005; Haneman, 1991; and Kahneman and Tversky, 1979).

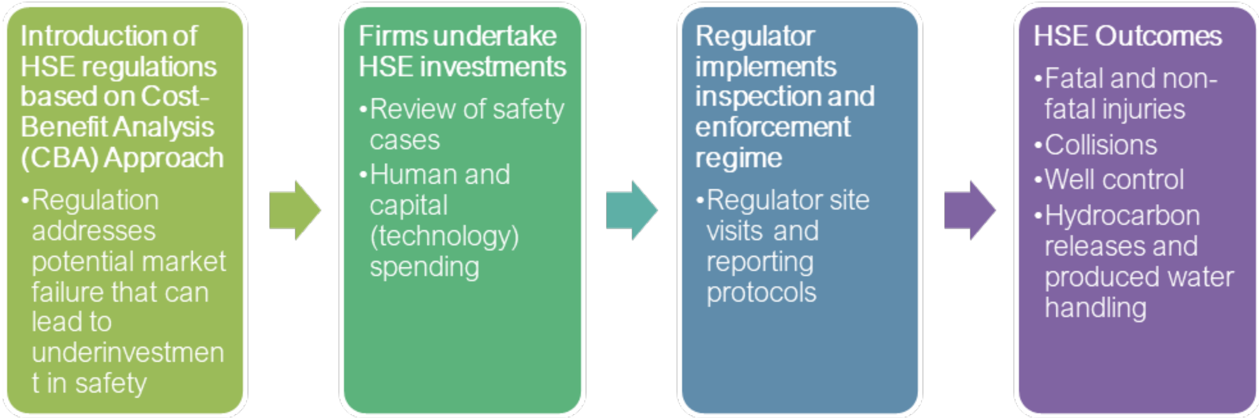
Standard economic theory predicts that the allocation of these collective HSE benefits, which comes in the form of lower injuries, cleaner water and lower emissions, should differ only to a minor extent when valued with either the WTP or WTA (Chilton et al., 2010). The difference between the WTP and 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). 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 individual marginal rates of substitution of wealth for the risk of death or injury or health impairment concerned (Chilton et al., 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).

Also, it has been argued that, because safety is a latent outcome that cannot be easily observed and interpreted by society due to the rarity of accidents and asymmetric information – moral hazard and adverse selection - society sometimes under or overestimates the probability of industrial accidents, thus failing to optimally provide for safety (Laffont, 1994; Lanoie 1991). To overcome this, it is proposed that the deployment of *ex-ante* safety regulation together with e*x-post* tort liability settlements may correct the apparent market failure (Kaplow & Shavell, 2002; Kolstad *et al*., 1990). It has also been argued that the overarching goal of public policy should be the minimization of the *sum* of accident costs and accident prevention costs (Posner, 2014).

Thus, to the extent that we can use policies to reduce the frequency and severity of industrial accidents, which include the risky nature of offshore operations, they become desirable from a welfare point of view to the point that we can demonstrate that the social optimality of safety is at a level which minimizes the sum of accident and accident prevention costs. To arrive at firm conclusions on the overall impact of HSE regulations, one needs to understand the means through which the institutional imposition of safety standards via channels such as Safety Cases, affects the supply and demand of safety in the offshore working environment, and ultimately safety outcomes (Acheampong et al., 2021). A Figure 1 illustrates, introducing HSE regulations premised on a cost-benefit approach (CBA) can address potential market failure that could lead to underinvestment in safety by operating firms. Firms subsequently undertake HSE investments encompassing both human and capital (technology) spending, among others. Following this, a regulator implements an inspection and enforcement regime which is evidenced through regulator site visits and reporting protocols imposed on firms. The overall effectiveness of the regime would then be evidenced by certain outcomes. Safety outcomes are governed by indicators such as (1) fatalities and injuries (fatalities, major injuries, minor injuries); (2) collisions (major collisions, major fires), (3) well control (major loss of well control, less than major loss of well control); and (4) hydrocarbon releases and produced water handling, among others (Hopkins, 2015).

In this regard, the CBA 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. The cost-benefit analysis (CBA) is a standard tool used by policymakers when considering environmental or safety policy actions. It is used more in circumstances whereby there is not an established good practice to provide or assess the impact of such actions on risk reduction measures straightforwardly (Hopkins, 2015; Špačková & Straub, 2015; Paltrinieri, 2012).

Figure 1 Conceptual framing of HSE input-output-outcomes



Source: Author's depiction

3 HSE costs, HSE performance measurement and monitoring in the offshore oil and gas industry

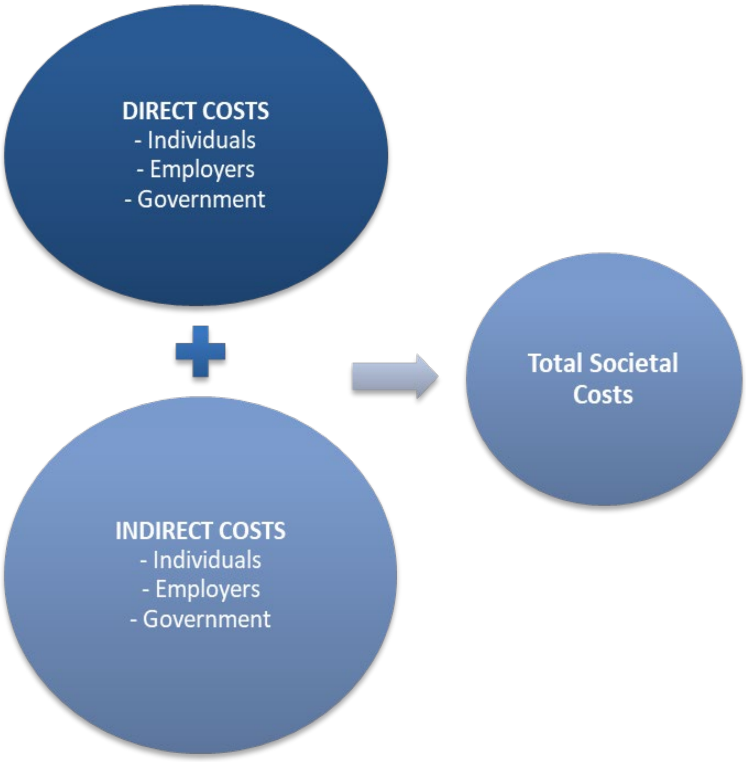
3.1 Cost classification

The economic impact of the accident and incidence costs in the offshore oil and gas industry is analysed within the cost framework shown in Figure 2. 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). The subject of debate often centres on the question of whether the removal of a hazard or risk dictated by the regulatory policy such as 'as low as reasonably practicable (ALARP)' in the United Kingdom, requires an expensive engineering or an inexpensive administrative cost (Maxwell, 2004; Aven & Vinnem, 2005).

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[4] 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.

[4] 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 2: Breakdown of economic costs of accidents



Source: Adapted from Health and Safety Executive (2011)

3.1.1 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[5] 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 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.

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

3.1.2 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. For example, 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). Likewise, 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 specific 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.

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.

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[6] in financial compensation paid by Occidental Petroleum, the operator of the platform, to the survivors and the families of the victims.

3.1.3 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.[7]

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

[6] 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]

[7] Details available at http://www.hmrc.gov.uk/helpsheets/e14.pdf [Accessed 20 December 2019]

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.

3.2 HSE performance measurement and monitoring

Various performance indicators are used to measure and benchmark HSE outcomes in most industries, including the offshore oil and gas industry. These indicators are used to (1) monitor how well the business or industry is performing – that is, whether trends are moving in the right direction; (2) raise awareness or to focus attention on particular industry issues, and (3) for public education purposes or campaigns. The performance indicators encompass both quantitative and qualitative measures or key performance indicators (KPIs) which are set against previously specified targets (Amir-Heidari et al., 2016; Kongsvik et al., 2011; Rozendal & Hale, 2000). These performance indicators are often utilised by companies' and regulators as part of their balanced scorecard system in order to monitor the health and safety risk levels that can materially impact them (Bergh et al., 2014).

Two main types of indicators are relevant for achieving the above-stated objects. These are classified as leading indicators and lagging indicators. Leading (proactive) indicators are those measures that used to identify potential problems before an accident occurs, whereas lagging (reactive) indicators actually measure accident or incident outcomes. That is, lagging indicators are focused or show the number and or severity of events (accidents or incidents) which have occurred whereas leading indicators can often be measured without an incident and accident occurring (Rozendal & Hale, 2000; Kaassis & Badri, 2018).

Historically in the oil and gas industry, HSE performance measures have traditionally focused on the physical aspects of operations such as technical and operational integrity resulting in injuries, cases of ill health or asset losses (Bergh et al., 2014; Rozendal & Hale, 2000). However, this has changed in the past decade with a greater focus on proactive actions such as measuring the safety climate via human and organisational factors, and emergency preparedness, among others (Sneddon et al., 2013; Olsen et al., 2015; Kvalheim et al., 2016).

Table 1 below summarises some of the leading and lagging indicators used in the offshore oil and gas industry.

Table 1 Summary HSE Performance Indicators

Leading (active) indicators	Lagging (reactive) indicators
• Safety audits and inspections • Behavioural and attitude surveys (psychosocial risk assessments) • Risk perception and cultural factors	• Lost time incidents/lost time injury frequency • Major and minor accidents • Hydrocarbon releases • Produced water handling

Source: Author's construct

4 Performance analysis and discussion of HSE trends in the UKCS

Here, we analyse the state of offshore safety via the performance analysis of the UK's offshore oil and gas industry in the Piper Alpha period. Data for the pre-Piper Alpha period is not available and thus cannot be analysed. Our objective here is to understand the trends in offshore injuries, accidents, incidents, spills and hydrocarbon releases – the key lagging indicators as shown in Table 1. The analysis is conducted using data plots and statistical tools such as moving averages.

This is done using data from the Hydrocarbon Releases (HCR) system and other industry databases. 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. A major release is defined as one with "potential to quickly impact outwith the local area, for example, affect the temporary refuge (TR), escape routes, escalate to other areas of the installation, causing serious injury or fatalities. A major leak, if ignited, would be likely to cause a "major accident", that is, it would be of a size capable of causing multiple casualties or rapid escalation affecting TR, escape routes, etc" (Health and Safety Executive, 2014). On the other hand, a significant release has the "potential to cause serious injury or fatality to personnel within the local area and to escalate within that local area, for example, by causing structural damage, secondary leaks or damage to safety systems. A significant leak, if ignited, might have the potential to cause an event severe enough to be viewed as a "major accident" or be of a size leading to significant escalation within the immediate area or module" (Health and Safety Executive, 2014). Likewise, a minor leak is one with "potential to cause serious injury to personnel in the immediate vicinity, but no potential to escalate or cause multiple fatalities. A minor leak, even if ignited, would not be expected to result in a multiple fatality event or significant escalation, but could cause serious injuries or a fatality local to the leak site or within that module only" (Health and Safety Executive, 2014).

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 predicated on a cost-benefit framework. 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).[8]

An extrapolation of some representative cases, systems or accidents is done to show how the CBA principles, which have been applied via channels such as the safety case regime in the UKCS, have led to improvements in core HSE performance indicators. The rest of the analysis in this section does not aim to exhaustively discuss all these elements (costs and unwanted events) but is meant to demonstrate the effectiveness of the economic approach for assessing HSE investment decisions, and eventually HSE outcomes.

4.1 Hydrocarbon releases analysis

Hydrocarbon leaks or releases are among the most important risk factors in offshore installations as they are often the precursor events for major accidents (Kongsvik et al., 2011). Hydrocarbon releases (HCRs) carry the risk of igniting fires and explosions if ignited - as they are volatile organic compounds - as well as oil spills, causing major environmental damage. These also can cause major fatalities, serious injuries, or substantial installation damage, as indicated by the 1988 Piper Alpha platform explosion in the United Kingdom (Acheampong & Akumperigya, 2018). Generally, there exists a relationship between the safety climate and HCRs – that is, increasing numbers of hydrocarbon leaks (lagging indicator) are associated with more negative safety climate scores (leading indicator) as indicated by Kongsvik et al. (2011), Vinnem & Røed (2015), and Damnjanovic and Røed (2016).

Regarding the trends, we find that 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 3. This decline 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. 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.

Also, as Figure 4 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

[8] See https://www.hse.gov.uk/osdr/index.htm

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.[9] 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 aspects of the industry, namely "asset integrity, competence, human factors, workforce engagement, helicopter safety, and marine transfer".[10]

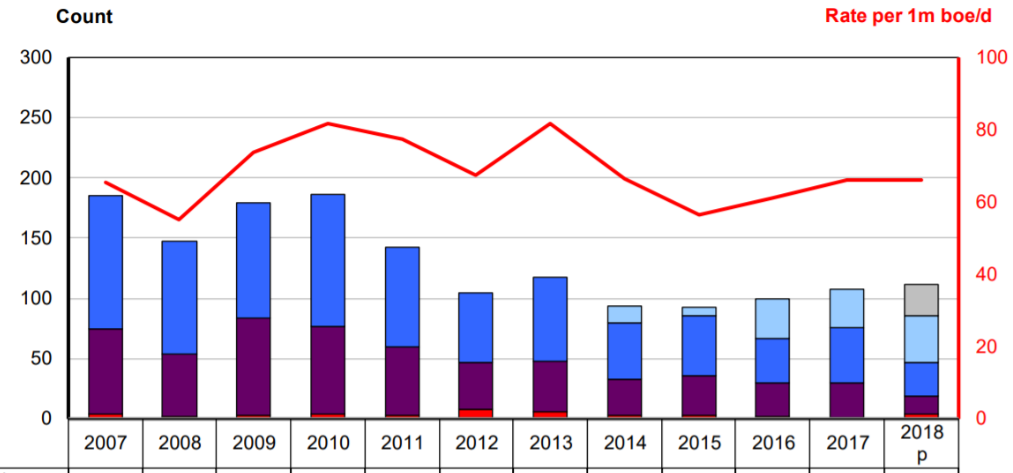
Furthermore, as depicted in Figure 5, incidents of significant and major releases are related to the age of the facility. Given the many years of operations on older platforms, one would expect most of the HCRs to come from these older installations whereas newer ones with lower operational years are 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 6. 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.

Figure 3: Reported offshore dangerous occurrences, 2007 – 2018

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

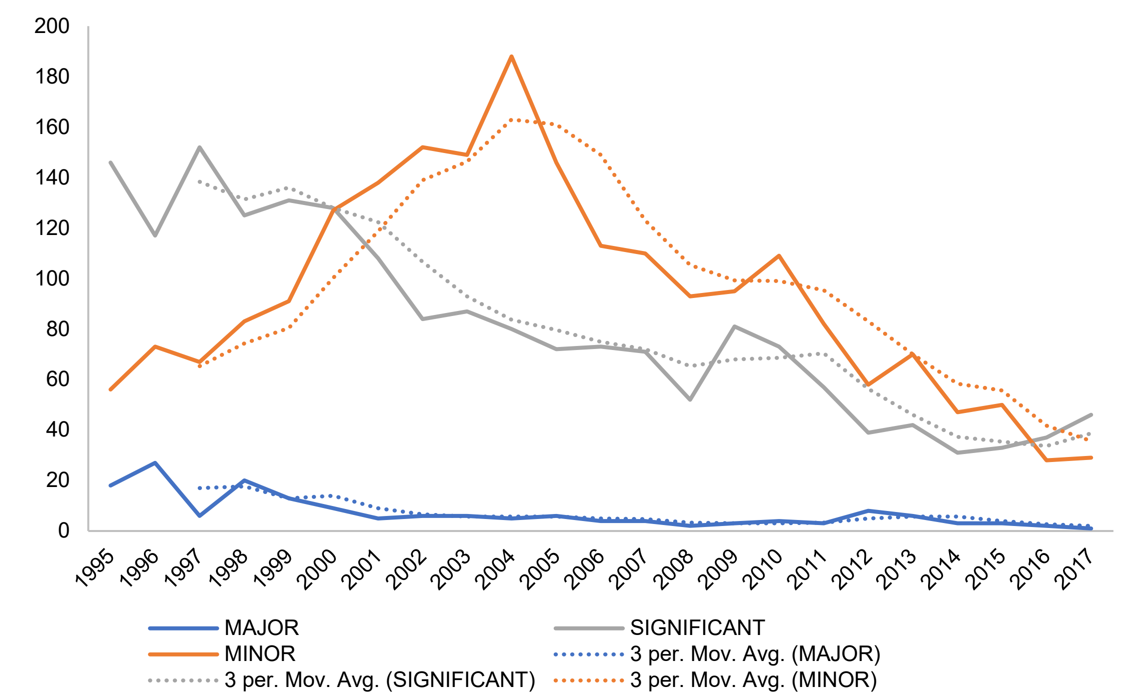
[10] Details available at https://www.stepchangeinsafety.net/about-step-change-safety/steering-groups [Accessed 25 January 2020]



	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

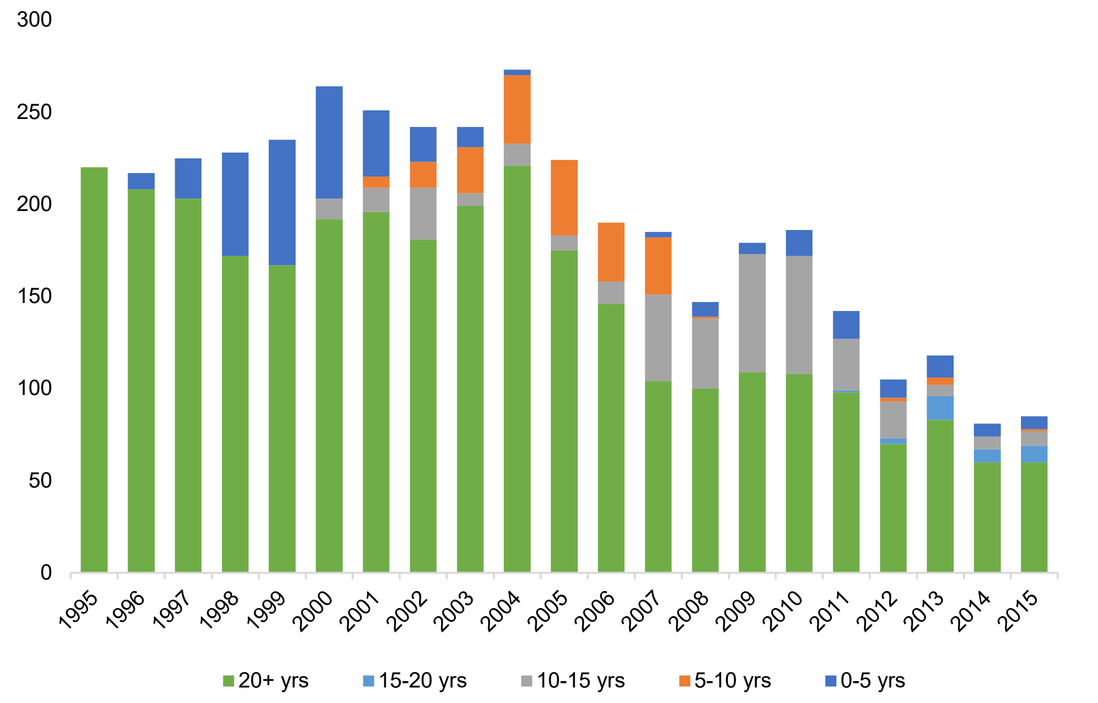
Source: Health and Safety Executive (2018)

Figure 4: HCRs by severity and moving averages, 1995-2017



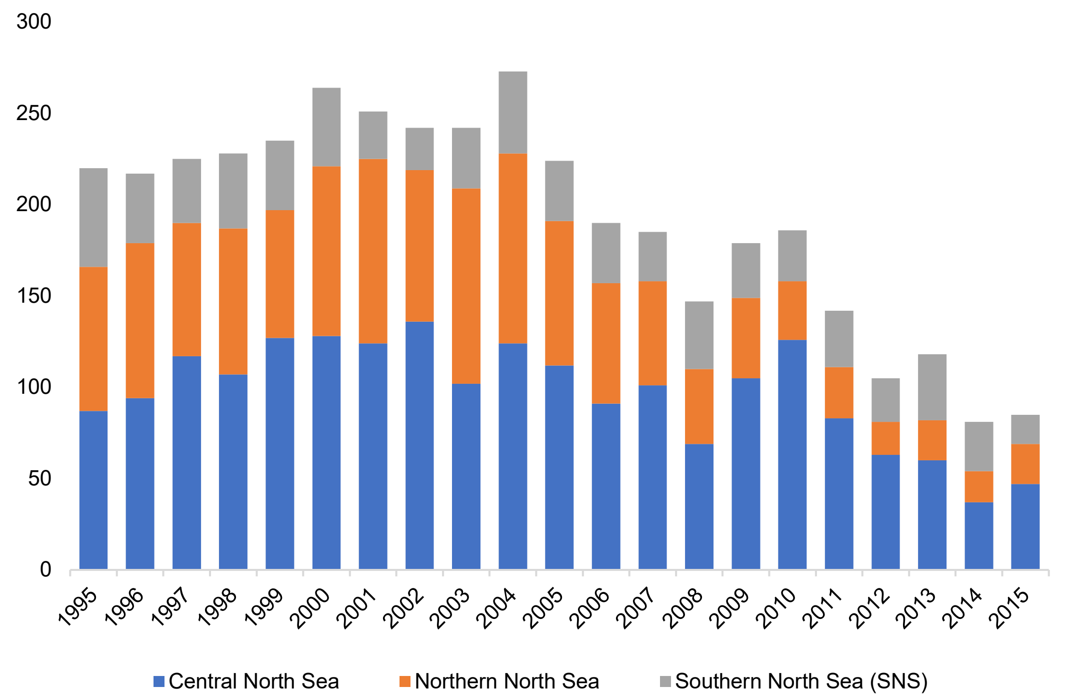
Data Source: Health and Safety Executive (2020)

Figure 5: UKCS HCRs by facility age, 1995-2015



Data Source: Health and Safety Executive (2020)

Figure 6: UKCS HCRs by location, 1995-2015



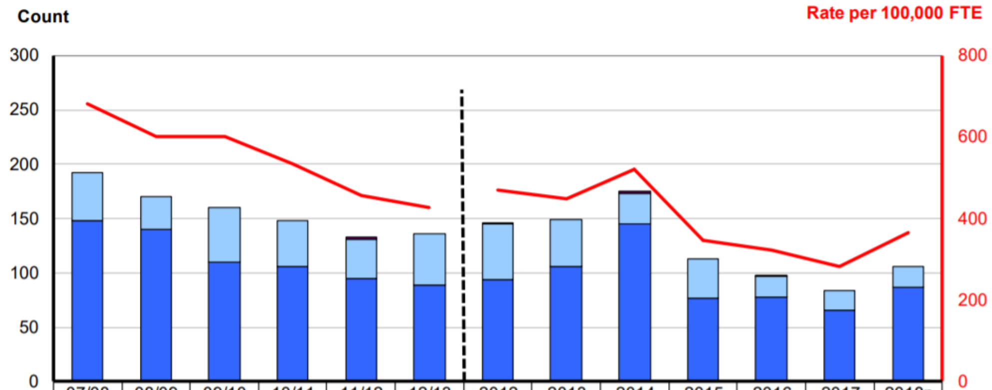
Data Source: Health and Safety Executive (2020)

4.2 Incidents and injury 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 7 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. Overall, injuries have been declining since 2007 with total injuries comprising fatalities, major, and over-3-day injuries have fallen by 45% from 192 injuries recorded in 2007 to 106 in 2018. 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.

Figure 7: Reported offshore injuries, 2007 – 2018

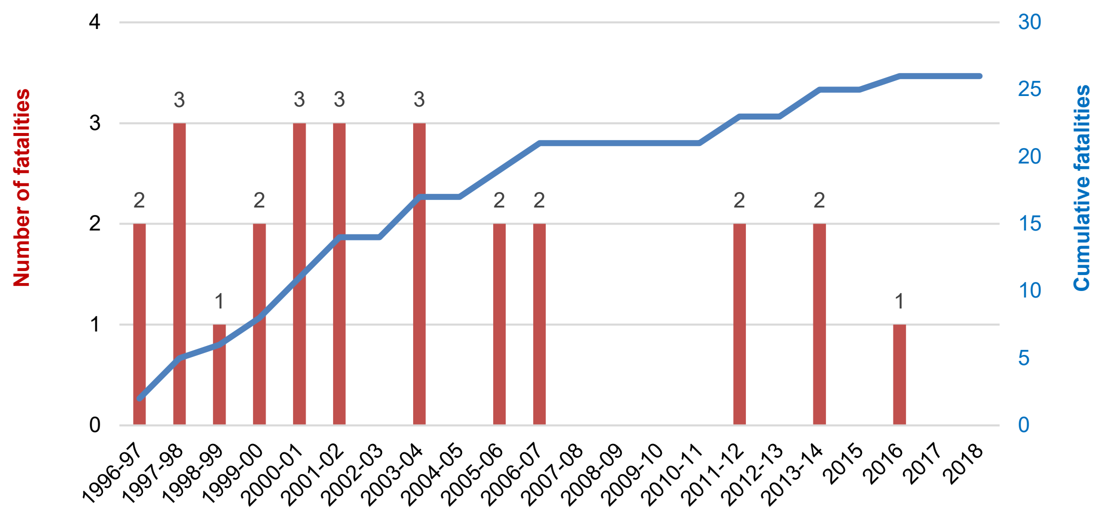


	07/08	08/09	09/10	10/11	11/12	12/13	2012	2013	2014	2015	2016	2017	2018p
Fatal	0	0	0	0	2	0	1	0	2	0	1	0	0
Major/Specified	44	30	50	42	36	47	51	43	28	36	19	18	19
Over-3-day/Over-7-day	148	140	110	106	95	89	94	106	145	77	78	66	87
Rate per 100,000 FTE	682	602	602	535	458	428	469	447	521	346	323	282	365

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

Source: Health and Safety Executive (2018)

Figure 8 Fatal injuries offshore



Data source: Oil and gas UK (2018)

4.3 Produced water handling and oil spill 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.[11] 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.

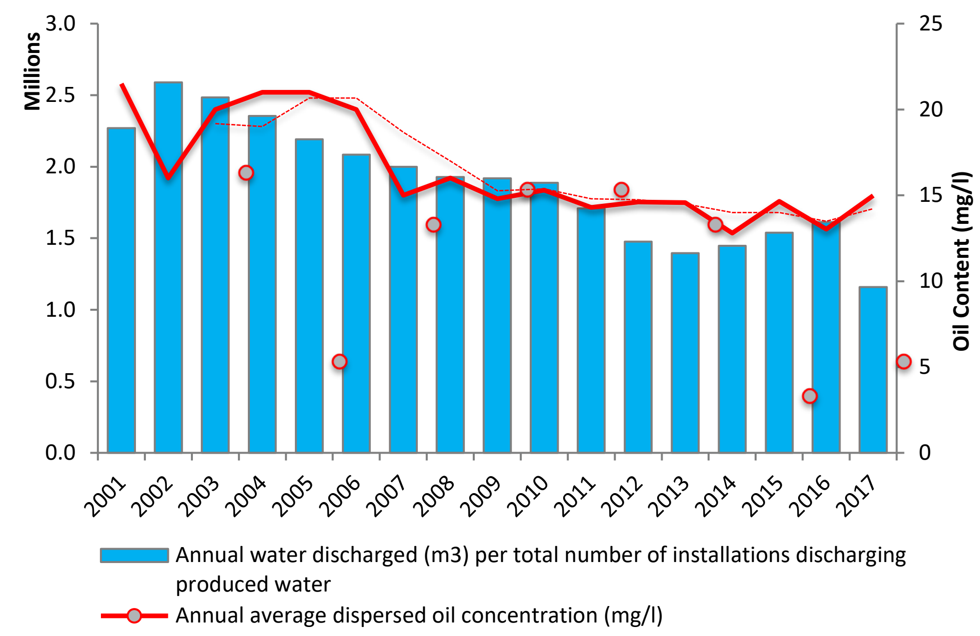
As an inextricable part of the recovery and separation processes for hydrocarbons, produced water is by far the largest waste stream by volume (Society of Petroleum Engineers, 2020; Danforth et al., 2019). In addition to formation water, produced water includes condensation water and reproduced injection 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 9 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 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.

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

Figure 9: Annual water discharged (m3) per total number of installations discharging produced water



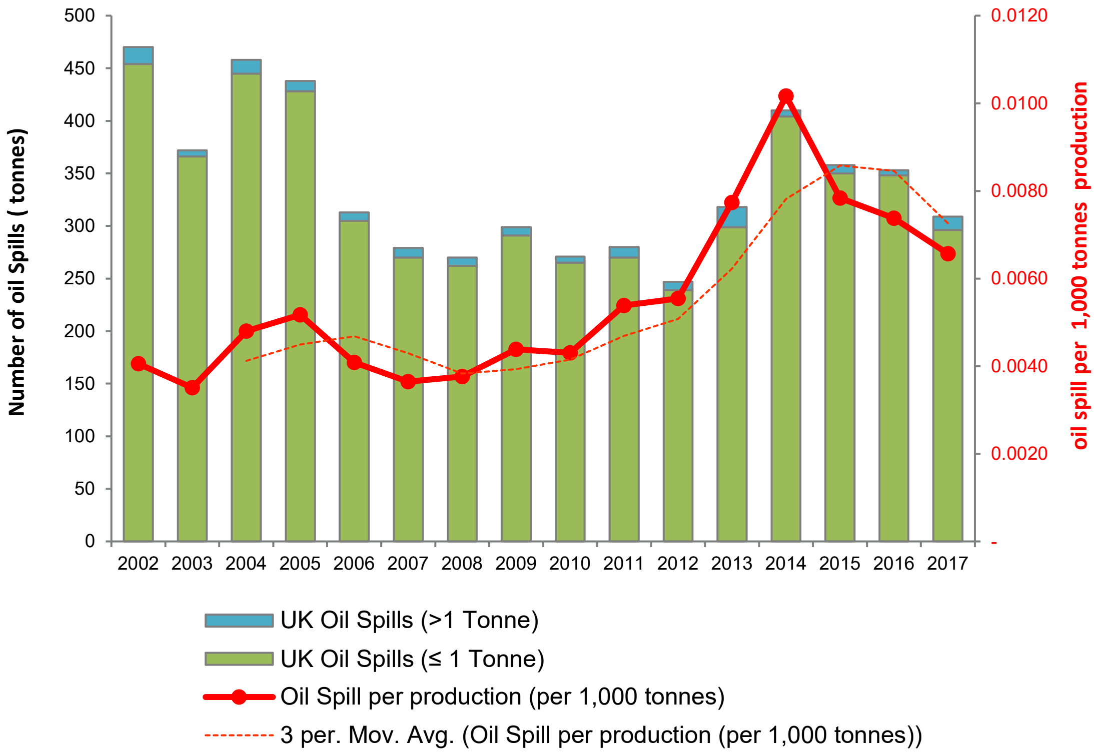
Also, Figure 10 provides a detailed breakdown of oil spills in the UKCS from 2002 to 2017. The amount of oil spilt has declined during the period under consideration after peaking at 470 spills in 2002 compared to 309 spill incidents in 2017. There has been an average of 340 spill incidents per year 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 (2013-2016) 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[12] 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.[13]

Figure 10: UKCS Oil Spill Statistics

[12] 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

[13] 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]



Data Source: OSPAR

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.[14] 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 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.[15]

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.[16] 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".[17]

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

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[14] 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

[15] ibid at 5.1

[16] Section 2 of the Regulations

[17] ibid 2(a)(b)(c)(d)

which members bear for each other's obligations.[18] 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 specific limit (Oil and Gas UK, 2012). OPOL has been accepted to represent 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 of these initiatives have collectively contributed to improving the safety performance of the UK's offshore oil and gas industry.

5 Conclusions

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. In an era of field maturity evidenced by dwindling field sizes and complex geological characteristics such as high pressure and temperature (HPHT) fields, is even more pertinent. It is with this at the back of our minds that we sought to carry out this study

In contextualising HSE issues, we argue that the industry should not perceive HSE compliance as being 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 whereby making the right HSE investments can benefit both the operator and society. This requires an appropriate framework to assess the probability of incident occurrences as well as the necessary contingency and mitigation plans. Thus, 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. Nevertheless, 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 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 utilised 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', and increased capital investments in facilities by operators and others, anchored on a more comprehensive cost-benefit framework. 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 of 2018, indicating a 100% reduction over the ten years. 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.

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[18] Details available at http://www.legislation.gov.uk/uksi/1988/1213/schedule/4/paragraph/23/made [Accessed 21 February 2020]

Overall, there has been a considerable improvement in safety in the United Kingdom's offshore oil and gas industry over the past two decades indicated by declining hydrocarbon releases (safety indicator), declining rates of incidents and injuries (health indicator), and produced water discharges (environment indicator). Nonetheless, the data also shows that the frequency of oil spill incidents (environment indicator) have increased by 62% compared to 2002 baseline levels. This is explained in part by several recent unplanned shutdowns between 2013-2016 and consequent reductions in production efficiency due to ageing infrastructure.

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