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Abstract

A raging debate currently persists regarding the future political economy of the UK Continental Shelf (UKCS) in relation to the prudence of new field developments in the province. Leading up to the COP26 global summit in November 2021, this debate had sharply centred on the pending application for consent to develop the Cambo field in the west of Shetland region of the province. Opposers of the field have called for a rejection of the application for consent to develop the field, citing the recent IEA and UN IPCC reports urging significant reductions in petroleum developments globally. Proponents of the field however argue that oil and gas remain vital to the UK economy as it transitions to net-zero. The controversy surrounding the field has led to the withdrawal of Shell Plc from its partnership with SP Energy on the Cambo field development project. Shell Plc cites economic viability concerns for its withdrawal. Industry observers however speculate that the field is commercially viable, and that Shell Plc's withdrawal is predicated on other considerations. This paper examines the economic viability of the Cambo field, finding that the field is inherently economically viable as per the established benchmark requirements for three commonly used investment metrics. Consequently, the paper recommends that owing to its high economic viability and low carbon intensity, the UK Government should consider approving the application for consent to develop the field, contingent on a stringent carbon emissions reduction programme for the field being implemented. This recommendation is consistent with a 'just' approach to energy transition, as well as the UK's policy of maximising economic recovery (MER) from the wider UKCS province.

1 Introduction

Petroleum exploration and production has been undertaken in the UK Continental Shelf (UKCS) since the 1960s. An estimated 45 billion barrels of oil equivalent (bboe) in petroleum resource has been produced over the six decades of activity in the province (OGUK, 2021.a). It is currently considered a mature basin, with an estimated 10 to 20 bboe of recoverable petroleum resource still to be produced over the next several decades (OGA, 2020).

The Cambo oil and gas field is located at about 125km to the west of Scotland's Shetland Islands in the UKCS, in water depths of about 1050m to 1100m (see map in Figure 1). Until recently, the field was co-owned by the private equity-backed explorer firm Siccar Point (SP) Energy and Shell Plc, with SP Energy being the majority shareholders with about 70% ownership stake. It was originally licensed for exploration in 2001. It has since undergone regular appraisal and as of 2021, has reached field development stage. Application for consent to develop the field is however currently pending with the UK Government. If approved, the field could start drilling as early as 2022 and production in 2025, with production projected over the next two decades, ending in 2050.

Figure 1: The Cambo field in the UKCS (Source: BBC, 2021.a)

Leading up to the United Nations Conference of the Parties in Glasgow in November 2021 (COP26) however, the issue of the application for consent to develop the Cambo field had generated much publicity and controversy relating to the political economy of the UKCS, with contrasting views about the prudence of developing new fields in the province within the wider context of decarbonisation, climate change mitigation and energy transition (see e.g. BBC, 2021.a; Reuters, 2021.a; AP News, 2021; New York Times, 2021; Bloomberg, 2021; Greenpeace UK, 2021; The Scotsman, 2021.a; The Herald Scotland, 2021.a).

On one hand of the debate, environmental protection groups (including Greenpeace UK, Friends of the Earth Scotland, ClientEarth, StopCambo.org.uk campaign, etc.) and political parties with green energy inclinations (e.g. the Scottish Greens) who act as opposers of the field had called for the field development consent application to be rejected by the UK Government, and for an immediate cessation of the development of all similar pending fields in the UKCS. They argue that development approval of the Cambo field is incompatible with the efforts needed to facilitate the transition away from fossil fuel production to clean and modern renewable energy generation (e.g. wind, solar, geothermal, etc.); and may in fact forestall consolidation of the gains already made in energy transition. In support of their argument, much had been cited of the heavily publicised recent reports by the IEA (2021) and

UN IPCC (2021) on the roadmap to net-zero by 2050 which highlight the urgency for radical reductions in the investment, development and/or production of oil and gas resources globally in order to decarbonise the global economy, transition to renewables and ultimately mitigate climate change. The IEA (2021) recommends that no new oil and gas exploration and development should be undertaken after 2021 if the world is to meet its climate change mitigation targets. Consistent with this finding, Welsby et al. (2021) also conclude that up to 60% of global oil and gas resources must remain unextracted in order to restrict global warming to the 1.5 ^{o}C target.

In November 2021, Nicola Sturgeon, the First Minister of Scotland, announced that the Cambo field "should not get the green light" (see e.g. BBC, 2021.b; The Scotsman, 2021.b; The Herald Scotland, 2021.b; The Times, 2021). Under the UK's devolved government architecture however, the power to regulate the UKCS upstream sector is within the remit of the UK Government and not its devolved administrations of which Scotland is a part. Whilst Scotland First Minister's views carry significant influence therefore, the ultimate decision regarding the approval or otherwise of the application for consent to develop the Cambo field rests with the UK Government which executes these powers through the UK Oil and Gas Authority (OGA). Nonetheless, Scotland First Minister's announcement has been widely regarded as a significant boost for the campaign of the opposers of the Cambo field.

On the other hand of the debate, proponents of the development approval of the Cambo field, which includes the UK Government,[1] the OGUK,[2] Aberdeen Chamber of Commerce,[3] and the Energy Transition Zone[4] amongst others have argued that development of the field is essential to (1) UK long-term energy security, (2) UK emission reduction targets and (3) the wider UK economy (see e.g. BBC, 2021.b; BBC, 2021.c). On energy security, they argue that the UK net-zero-consistent oil and gas demand and production projections, as produced by the UK Committee on Climate Change (UK Committee on Climate Change, 2021), shows that over the next few decades, UK net-zero-consistent demand outstrips projected production, with UK petroleum import dependency remaining at about 50% in that period (see Figure 2). The projected production by the committee on climate change includes production from the Cambo field. As domestic UK demand outstrips UK domestic production (supply), failure to approve the development of the Cambo field would exacerbate the UK's petroleum import dependency, hence diminishing UK energy security. They argue that the Cambo field would enhance UK energy security by delivering several million volumes of domestically produced oil and gas resource to the UK energy mix (see e.g. UK Government, 2021.a; SP Energy, 2021.a; SP Energy, 2021.b). It is estimated for example that the natural gas resource in the Cambo field is sufficient to power over 1.5 million UK homes for a year (SP Energy, 2021.b).

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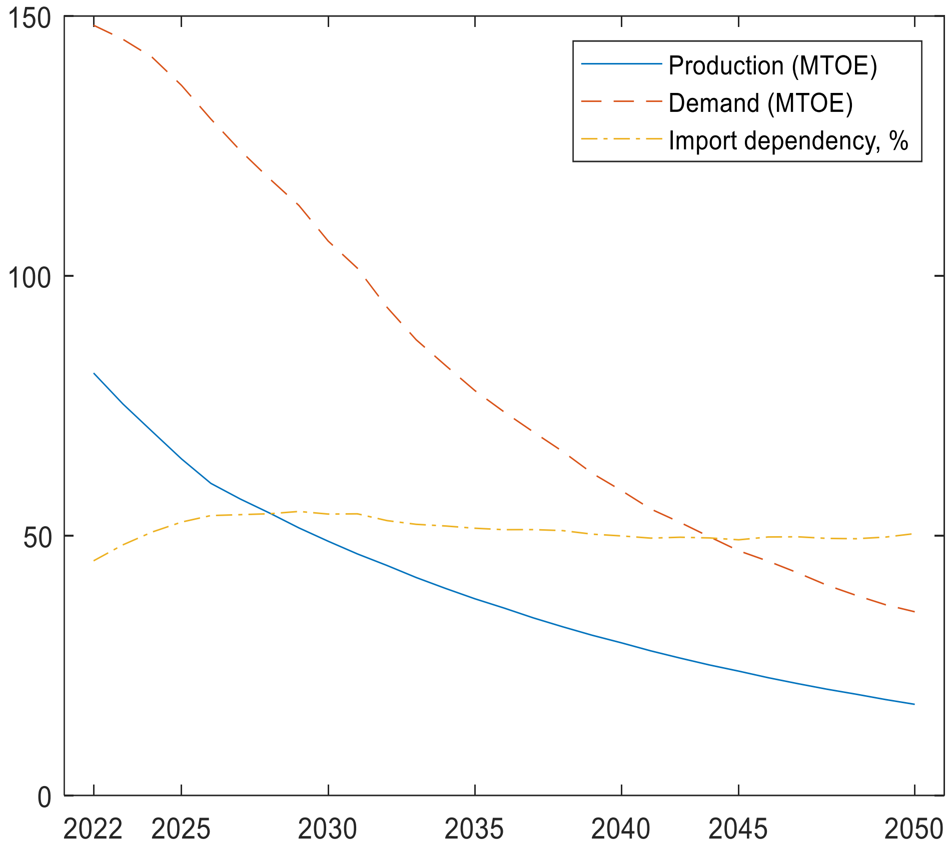
[1] The UK Energy Minister Greg Hands] and the Scottish Secretary of the UK Government Alistair Jack had both expressed strong support for the development of the Cambo field, indicating that it should "100%" get the go-ahead (see BBC, 2021.b; BBC, 2021.c)

[2] External relations director of the OGUK Jenny Stanning had said that "the UK will continue to need new oil and gas projects if (it is) to protect security of supply, avoid increasing reliance on imports and support jobs." (see BBC, 2021.c)

[3] The chief executive of the Aberdeen Chamber of Commerce, Russell Borthwick, had suggested that cancellation of the development of the Cambo field is akin to a knee-jerk reaction to climate change, and may have severe implication on employment in oil and gas communities in Scotland and across the UK. (see BBC, 2021.c)

[4] Chairman of Aberdeen's Energy Transition Zone, Sir Ian Wood, had said that the UK should "not create an adverse investment environment at this crucial moment in (its) energy transition journey." (see BBC, 2021.c)

Figure 2: UK net-zero consistent oil and gas projected production, demand and import dependency. Projected production includes projected output from the Cambo field (source: author plot using data provided by OGA, 2021)



On UK emission reduction targets, proponents of the Cambo field argue that non-approval of its development may lead to increased UK petroleum import dependency. The UK would be effectively substituting Cambo oil and gas output for imported output from other jurisdictions; effectively therefore 'offshoring' what would have been upstream Cambo field carbon emissions to those jurisdictions. This is the so-called 'carbon leakage' scenario. Proponents of the Cambo field argue that the jurisdictions from which the UK imports petroleum are often less regulated with respect to upstream carbon emissions and have higher carbon intensity as a result. Increased imports from those jurisdictions therefore lead to an undermining of the UK's contribution to global emissions. In this regard, proponents of the Cambo field have argued that it is prudent to develop and produce UK domestic oil and gas rather than increase UK petroleum imports, as UKCS regulations on upstream emissions are more stringent.[5] The Cambo field has for instance undergone a comprehensive environmental impact assessment (see UK Government, 2021.a; SP Energy, 2021.a), with indications being that upstream emissions from the field would be on average 50% lower than pre-existing and currently producing UKCS fields. Also, the planned development of the Cambo field accounts for the possibility of taking power from renewable energy sources (e.g. wind power) when that is made

[5] Chief executive of SP Energy Jonathan Roger had said that the "UK is at risk of damaging its economy and increasing imports with a higher carbon impact if new (UKCS) developments are not brought forward." (BBC, 2021.c)

possible, hence potentially further reducing its upstream operational emissions significantly (UK Government, 2021.a; SP Energy, 2021.a; SP Energy, 2021.b).

On impacts to the wider UK economy, it is estimated that the upstream UKCS petroleum sector supported over 250,000 direct, indirect and induced jobs in the UK prior to the COVID-19 pandemic (OGUK, 2021.b),[6] hence underscoring the significant importance of the sector to the wider UK economy. SP Energy estimates that the Cambo field would contribute 1000 direct jobs as well as thousands more indirect and induced jobs in the UK economy (SP Energy, 2021.b). Proponents of the Cambo field argue that failure to approve the consent for the development of the field would amount to market signalling that reduces the competitiveness of the UKCS as a major global petroleum investment and production hub, more so in an environment where capital rationing is prevalent in the global upstream petroleum sector (Osmundsen et al., 2022). For the UK Government also, significant tax revenues could be foregone. Proponents of the Cambo field have argued that development approval of the field is compatible with a 'just' approach to energy transition; where energy transition is gradually facilitated and managed within the context of the current and evolving UK energy security needs as well as safeguarding of the wider UK economy. The stance of the opposers of the field has been labelled as a 'cliff-edge' approach to energy transition (see OGUK, 2021.b).

In December 2021, Shell Plc which had 30% ownership stake in the Cambo field announced its withdrawal in the partnership it had with SP Energy on the Cambo field development project (see BBC, 2021.c; Reuters, 2021.b; Financial Times FT, 2021), citing a weak economic case as its reason. The company stated that *"after comprehensive screening of the proposed Cambo development, we have concluded the economic case for investment in this project is not strong enough at this time"*. Shell Plc's decision has been regarded as a major win for opposers of the Cambo field, with the environmental protection group Greenpeace UK stating that Shell Plc's decision to withdraw signifies the "deathblow" to the Cambo field's development. Some industry observers however speculate that Shell Plc's decision to withdraw from the Cambo field is predicated on a goal of mitigating the reputational damage it suffers from battling with environmentalists for the application for consent to develop the field rather than the economic viability of the field.

The controversy surrounding the field has meant that there is currently significant uncertainty as to whether it progresses to development or not. The most objective measure for justifying development or otherwise of the field is its economic viability. In this paper, we examine the economic viability of the Cambo field in detail. We construct a mathematical optimisation model and use credible and publicly available data on the field as input to the model to examine its economic viability. The model takes into consideration (1) the UK upstream petroleum tax regime; and (2) charges for upstream carbon emissions. With respect to taxation, we capture the existing UK taxation regime for upstream petroleum operations. We incorporate UK tax components such as the Ring Fence Corporation Tax (RFCT) (UK Government, 2021.b), which is currently levied at 30% of field taxable income; and the Supplementary Charge (UK Government, 2021.c), which is currently levied at 10% of field taxable income after Investment Allowance deductions. We also capture UK upstream tax allowance components such as the

[6] Direct jobs relate to employment 'directly involved in the production of oil and gas in the UK'. Indirect jobs relate to 'employment supported in companies from across the wider supply chain who supply goods and services in support of oil and gas production in the UK'. Induced jobs relate to 'employment supported by the expenditure of income from the oil and gas sector e.g. accommodation, services, etc.' (OGUK, 2021.c).

Capital Allowances for capital expenditures; and the Investment Allowances for the Supplementary Charge, which is currently set at 62.5% of capital expenditures (UK Government, 2021.d). With respect to upstream carbon emission charges, recent evidence suggests that prudent UKCS operators are incorporating these charges in their financial models for assessing the economic viability of fields (Wood Mackenzie, 2021; OGUK, 2021.a; Thorne and Mittal, 2019; Mu, 2019).[7] We therefore account for these charges in our model.

We find that the Cambo field is inherently economically viable and of low upstream carbon intensity compared to crude oil grades from countries where the UK imports crude. We therefore recommend that the UK Government should proceed with approval of the application for consent to develop the field, on condition that the field operators implement a stringent upstream carbon emissions reduction programme. We argue that approval of the Cambo field development would be consistent with the ethos of a 'just' approach to energy transition whilst at the same time being compatible with the UK Government's policy of maximising economic recovery (MER) from the UKCS province.

The rest of the paper is organised as follows; Section 2 introduces our methodology, with a description of our model and underlying assumptions. Section 3 introduces our data whilst Section 4 introduces our results. Section 4.2 concludes the paper.

2 Methodology

2.1 Model setting and assumptions

In this section, we introduce a mathematical optimisation model to determine the optimal operation and economic viability of the Cambo field using the net present value (NPV) investment metric. This metric is consistent with the stated MER goal of the UK Government and allied oil and gas industry institutions and has been widely used to assess the economic viability of oil and gas fields (OGA, 2016; Abdul-Salam et al., 2021; Olsen and Osmundsen, 2011; Osmundsen et al., 2022).[8] We also determine two other investment metrics for the field, namely (1) the NPV to investment index metric (i.e. NPVI index); and (2) the internal rate of return metric (i.e. IRR).

With regards the treatment of taxation in our model, it is important to underscore that the UK Government makes a distinction between different types of upstream petroleum investors for tax application purposes. This has important implications for the economic viability of fields in the UKCS province. Consequently, modelling the economics of oil and gas fields in the province requires explicit assumptions about the type of investors being considered, namely whether the investors have existing and sufficient tax paying positions with the UK Government Treasury to the extent that they are eligible for substantive first-year capital and investment tax reliefs, or not. We assume that SP Energy, the majority shareholders in the Cambo field, is unable to benefit full and immediate first-year capital and investment tax reliefs

[7] Where appropriate, we use the term 'investor' and 'operator' interchangeably

[8] The OGA regulates the upstream oil and gas sector in the UK. OGA (2016) define economically recoverable reserves as 'those resources which could be recovered at an expected (pre-tax) market value greater than the expected (pre-tax) resource cost of their extraction, where costs include both capital and operating expenditures but exclude sunk costs and costs (such as interest charges) which do not reflect current use of resources. In bringing costs and revenues to a common point for comparative purposes a 10% real discount rate will be used'.

for two reasons. First, SP Energy is a relatively small firm. It is therefore unlikely that the company would have a sufficient pre-existing tax paying position with the UK Government Treasury to warrant full and immediate first-year tax reliefs. Second, the recent history of global oil prices has meant that the net cash flow of the whole UKCS sector had been substantially negative although this is changing with the current relatively high level of oil and gas prices. For the Cambo field therefore, we assume that capital and investment tax reliefs would be staggered over the production horizon of the field. The implication of our assumption regarding the treatment of tax is that the economics of the Cambo field would be diminished relative to a scenario where the investor is assumed to have existing tax paying positions for full and early tax reliefs. In this regard, our approach to the assessment of the economic viability of the Cambo field may be presumed to be conservative.

2.1.1 Equations defining tax allowances

Following the above model setting and assumptions, let t represent time. Consequently, let x_t^{oil} (million barrels; mmbbl) and x_t^{gas} (million standard cubic feet; mmscf) represent endogenous oil and gas production profiles respectively. Also let q_t^{oil} (mmbbl) and q_t^{gas} (mmscf) represent the corresponding exogenous Cambo field production profiles for oil and gas respectively. Data on the exogenous pre-determined production profiles are obtained from the environmental impact assessment report of the Cambo field, as published by the UK Government (see UK Government, 2021.a, page 465; SP Energy, 2021.a, page 465). Now let α_t represent an endogenous binary variable indicating the endogenous status of production in period t, such that;

$$\left(x_t^{oil} + x_t^{gas}\right) - BigM \cdot \alpha_t \leq 0 \;\; \forall \;\; t \tag{1}$$

$$\sum_t \left(x_t^{oil} \cdot \alpha_t\right) \leq \sum_t q_t^{oil} \tag{2}$$

$$\sum_t \left(x_t^{gas} \cdot \alpha_t\right) \leq \sum_t q_t^{gas} \tag{3}$$

$$0.9 \cdot q_t^{oil} \cdot \alpha_t \leq x_t^{oil} \leq 1.1 \cdot q_t^{oil} \cdot \alpha_t \;\; \forall \;\; t \tag{4}$$

$$0.9 \cdot q_t^{gas} \cdot \alpha_t \leq x_t^{gas} \leq 1.1 \cdot q_t^{gas} \cdot \alpha_t \;\; \forall \;\; t \tag{5}$$

where $BigM$ is an exogenous large positive number.[9] Equation (1) captures the endogenous production status of the Cambo field such that the binary variable α_t takes a value of 1 if production in period t is endogenously determined to be optimal (i.e. when $x_t^{oil} > 0$ and/or $x_t^{gas} > 0$), and 0 otherwise. Equations (2) – (3) ensure that the endogenous total produced oil and gas do not exceed the published exogenous quantities. Constraints (4) – (5) ensure that for periods where endogenous production occurs, the endogenously produced oil and gas quantities are within a 10% deviation of the published exogenous oil and gas production

[9] Use of the large positive number $BigM$ in equation (1) is an integer programming formulation trick that forces the associated binary variable to take a value of 1 when field production is nonzero.

profiles. These constraints allow perturbations in the endogenously determined production profiles of oil and gas in response to stochastic price fluctuations.

Now production only occurs when field development is undertaken. Hence let β represent an endogenous binary variable representing the development status of the Cambo field, such that;

$$\sum_t (\alpha_t) - BigM \cdot \beta \leq 0 \tag{6}$$

Equation (6) captures the endogenous development status of the field such that the binary variable β takes a value of 1 only if endogenous production ever occurs (i.e. if $\alpha_t > 0$ in any period).

Now let CE_t^{annual} ($ million; $m) and CE^{total} ($m) represent exogenous and endogenous positive variables respectively indicating the annual and total Cambo field capital expenditures incurred for field development. These include drilling and completion expenditures of production and completion wells as well as the expenditures accompanying the installation of associated infrastructure (e.g. pipelines, manifolds, processing hubs, etc.). Consequently, the Cambo field capital and investment allowances for tax relief purposes in any period, per the existing UK taxation regime, can be determined and constrained in the model as follows;

$$CE^{total} = \sum_t \left(CE_t^{annual} \cdot \beta\right) \tag{7}$$

$$CA_{t=1}^{total} = CE^{total} \cdot \beta \;\forall\; t = 1 \tag{8}$$

$$IA_{t=1}^{total} = ia \cdot CE^{total} \cdot \beta \;\forall\; t = 1 \tag{9}$$

$$CA_{t+1}^{total} = (CA_t^{total} - CA_t^{annual}) \cdot \beta \quad \forall\; t = 2, \dots, T \tag{10}$$

$$IA_{t+1}^{total} = \left(IA_t^{total} - IA_t^{annual}\right) \cdot \beta \;\;\forall\;\; t = 2, \dots, T \tag{11}$$

$$CA_t^{annual} \leq CA_t^{total} \;\forall\; t \tag{12}$$

$$IA_t^{annual} \leq IA_t^{total} \;\forall\; t \tag{13}$$

where

Endogenous variables	**Description**
CA_t^{total}	Total capital allowance in period t ($m)
IA_t^{total}	Total investment allowance in period t ($m)
CA_t^{annual}	Capital allowance applied for tax relief purposes in period t ($m)
IA_t^{annual}	Investment allowance applied for tax relief purposes in period t ($m)

Exogenous parameters	Description
ia	Exogenous investment allowance rate (%)

Equation (7) determines the total capital expenditure of the field, which is incurred only if production is endogenously determined to occur, as shown in the accounting of the binary variable β. Equations (8) – (9) capture the first-year capital and investment allowance levels. Equations (10) – (11) capture the allowance levels in subsequent periods, which involves deductions of the allowances allocated and applied in previous periods. Equations (12) – (13) ensure that the capital and investment allowances applied for tax relief purposes in any period do not exceed the total available for that period.

2.1.2 Equations defining cashflows

The following equations outline definitions and constraints capturing the income statement of the Cambo field in each operational period t, taking into account the capital and investment allowances determined above;

$$R_t = \left(P_t^{oil} \cdot x_t^{oil} + P_t^{gas} \cdot \gamma \cdot x_t^{gas}\right) \cdot \alpha_t \ \forall \ t \tag{14}$$

$$PTP_t = \left(R_t - OE - P_t^{crbn} \cdot \delta_t^{crbn} \cdot x_t\right) \cdot \alpha_t \ \forall \ t \tag{15}$$

$$TI_t = PTP_t - CA_t^{annual} \ \forall \ t \tag{16}$$

$$TICT_t = TI_t \ \forall \ t \tag{17}$$

$$TISC_t = TI_t - IA_t^{annual} \ \forall \ t \tag{18}$$

$$tax_t = \max[0, rfct \cdot TICT_t + sc \cdot TISC_t] \ \forall \ t \tag{19}$$

$$CF_t = PTP_t - tax_t \ \forall \ t \tag{20}$$

where

Endogenous variables	Description
R_t	Total revenues in period t (\$m)
PTP_t	Pre-tax profit in period t (\$m)
x_t	Sum of produced oil (mmbbl) and gas (mmscf) in period t, all converted to mmboe
EC_t	Carbon emissions charge in period t (\$m)
TI_t	Taxable income in period t (\$m)

$TICT_t$	Taxable income for Ring Fence Corporation Tax in period t (\$m)
$TISC_t$	Taxable income for Supplementary Charge in period t (\$m)
tax_t	Tax paid in period t (\$m)
CF_t	Cashflow in period t (\$m)
Exogenous parameters	**Description**
P_t^{oil}	Real price of oil in period t (\$/bbl)
P_t^{gas}	Real price of gas in period t (\$/mmbtu)
γ	Conversion factor of gas price from \$/mmbtu to \$/scf
P_t^{crbn}	Real price of carbon emissions in period t (\$/tCO_2e)
δ_t^{crbn}	Carbon intensity of the Cambo field in period t (tCO_2e/boe)
OE	Cambo field operating expenditure (\$m)
$rfct$	Ring fence corporation tax (%)
sc	Supplementary charge (%)

Equation (14) defines annual revenues which are a function of the real price of oil and gas. Equation (15) defines pre-tax profits, which include deduction of operating expenditures and carbon emission charges. We assume average operating expenditures which are non-variant over time, consistent with the cost structures of petroleum operations in the UKCS province (Abdul-Salam et al., 2021). Equation (16) defines the overall taxable income, which involves deduction of capital allowances to provide tax reliefs. Equation (17) defines taxable income for Ring Fence Corporation Tax. Equation (18) defines taxable income for Supplementary Charge, which involves further deduction of investment allowances to provide additional tax reliefs. Minimum tax paid in each period is 0, but maximum is levied as shown in equation (19). Equation (20) captures cashflows for each operational period. These cashflows are used in the determination of the overall objective of maximising NPV, as shown next.

2.1.3 Objective function – NPV; and derived metrics NPVI index and IRR

As previously indicated, we assume in the first instance that the objective of the Cambo field investor SP Energy (and its project partners) is to maximise the NPV (\$m) of the field as follows;

$$\text{maximise} \quad NPV = -CE^{total} + \sum_t \frac{CF_t}{(1+r)^{t-1}} - \frac{DE^{total} \cdot \beta}{(1+r)^{\omega-1}} \tag{21}$$

where r is the discount rate; ω is the endogenous terminal period; and DE^{total} is the total decommissioning expenditure. A project is deemed to be economically viable when the NPV is positive (Brealey and Myers, 2011; Copeland and Weston, 2005). The solution to equation (21) accounts for the constraints and definitions presented in equations (1) – (20). Note that other important but more nuanced definitions and constraints are imposed in the model to better reflect the reality of upstream petroleum operations and economics in the UKCS. For example, we impose constraints to allow only sequential production, so that a start-stop-start production sequence is disallowed (Abdul-Salam et al., 2021). By this constraint, we have implicitly assumed that the cost of stopping and restarting the Cambo field is prohibitive, so that once cessation of production occurs, restart is not permissible, and decommissioning must occur. Additionally, we impose constraints to prevent implicit subsidies by way of improper allocation of capital and/or investment allowances for tax relief purposes. To preserve space however, further of such definitions and constraints in our model are not presented here. The full model detailing all equations and constraints is available upon request.

As previously mentioned, indications are that oil and gas companies also use other investment metrics to determine the economic viability of their projects. In particular the NPVI index and the IRR metrics are commonly used (Osmundsen et al., 2022). Accordingly, we calculate the NPVI index metric as follows;

$$NPVI = \frac{NPV}{CE^{total}} \tag{22}$$

In equation (22), the NPV and capital expenditures are known from the NPV model solution. Economic viability occurs when the NPVI index metric is 0.3 or greater (OGA, 2018.a; Abdul-Salam et al., 2021; Osmundsen et al., 2022). Osmundsen et al. (2022) observe that the NPVI index metric is predominantly used by major international oil companies in periods when oil prices are relatively stable. We also calculate the IRR criterion as follows;

$$-CE^{total} + \sum_{t} \frac{CF_t}{(1 + IRR)^{t-1}} - \frac{DE^{total}}{(1 + IRR)^{T-1}} = 0 \tag{23}$$

In equation (23), the IRR is the only unknown variable, with all other quantities known from the NPV model solution. The greater the IRR, the more economically viable is a project. According to the oil and gas consultancy firm Wood Mackenzie, petroleum companies have a high level of of IRR requirement, “with 15 percent considered the standard industry benchmark for a robust project” (Osmundsen et al., 2022).

2.2 Stochastic versus deterministic prices

The choice of treatment of prices, whether stochastic or deterministic, is an important determinant of model results. A stochastic treatment is often preferable for important price processes in models because it accounts for uncertainty in the intertemporal realisations of these prices. A mean reverting stochastic price process is often assumed for natural resources including petroleum (Abdul-Salam, 2022; Bessembinder et al. 1995; Gibson and Schwartz, 1990; Schwartz, 1997). In this paper we assume a mean price reverting oil price process for two reasons. First, the Cambo field is a predominantly oil field, with estimates of reserves being 209.90 mmboe oil (i.e. 92.00% of reserves) and 18.32 mmboe gas (i.e. 8.00% of reserves) (see UK Government, 2021.a; SP Energy, 2021.a). Second, the empirical parameters of the mean reverting oil price process are available to draw from the literature. Accordingly, the mean price reverting stochastic oil price process in our model is given as follows (see Abdul-Salam, 2022; Gillespie, 1996; Smith, 2010);

$$P_{t+1}^{oil} = e^{-\rho\Delta t} \cdot P_t^{oil} + (1 - e^{-\rho\Delta t}) \cdot p_{eqm} + \sigma\sqrt{\frac{(1 - e^{-2\rho\Delta t})}{2\rho}} \cdot \varepsilon_t \quad (24)$$

$$\varepsilon_t \sim N\left(0, \sqrt{\Delta t}\right)$$

where p_{eqm} is the real long-run equilibrium oil price (\$/bbl); ρ is the oil price reversion speed (unitless), which is the speed at which short-run price shocks dissipate to return oil prices to their long-run equilibrium; σ is a measure of the oil price volatility (\$/bbl); and ε_t is a random shock variable which is assumed to be normally distributed. Negative prices are realisable with the mean reversion process in equation (24) hence the absolute of the yielded prices are taken. Gas revenues and carbon emission costs constitute a small component of the economics of the Cambo field. For simplicity therefore, we assume a triangular distribution for the real stochastic realisations of the annual prices of gas P_t^{gas} and carbon P_t^{crbn}. The stochasticity in the oil, gas and carbon price processes lends to a Monte Carlo application of our model. Monte Carlo Analysis is a simulation-based risk modelling technique that yields the expected values and confidence intervals of important model metrics as a result of many simulations that capture the collective impact of price uncertainties. Our model is solved for 10000 price simulations, with each simulation having a different stochastic realisation of oil, gas and carbon prices over the production horizon of the Cambo field (i.e. 2025 – 2050).

2.3 Model implementation

Our model is formulated in the General Algebraic Modelling System (GAMS) software and language as a Mixed Integer Non-Linear Programming (MINLP) problem. The model is solved using the LINDOGLOBAL solver in GAMS. This solver ensures globally optimal solutions are obtained.

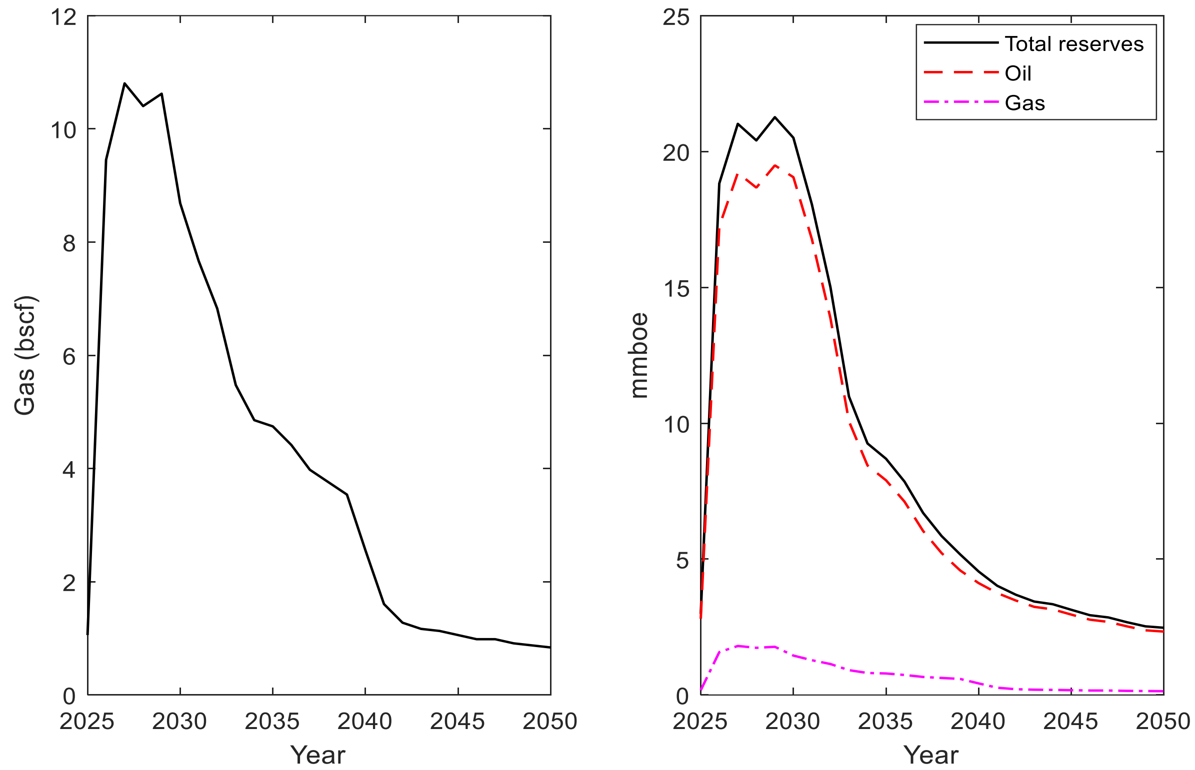
3 Data

3.1 Production and carbon intensity data

We use the oil and gas production profile data for the Cambo field as provided in the field environmental impact assessment report published by the UK Government (see UK Government, 2021.a, page 465; SP Energy, 2021.a, page 465). These profiles are shown in Figure 3. Aggregate production of oil and gas over the lifetime of the field are 209.90 mmboe and 18.32 mmboe (i.e. 109.68 billion standard cubic feet; bscf) respectively, making a total of 228.22 mmboe of reserve volume.[10] We also use the carbon intensity data for the field as published in the same report (see Figure 4).

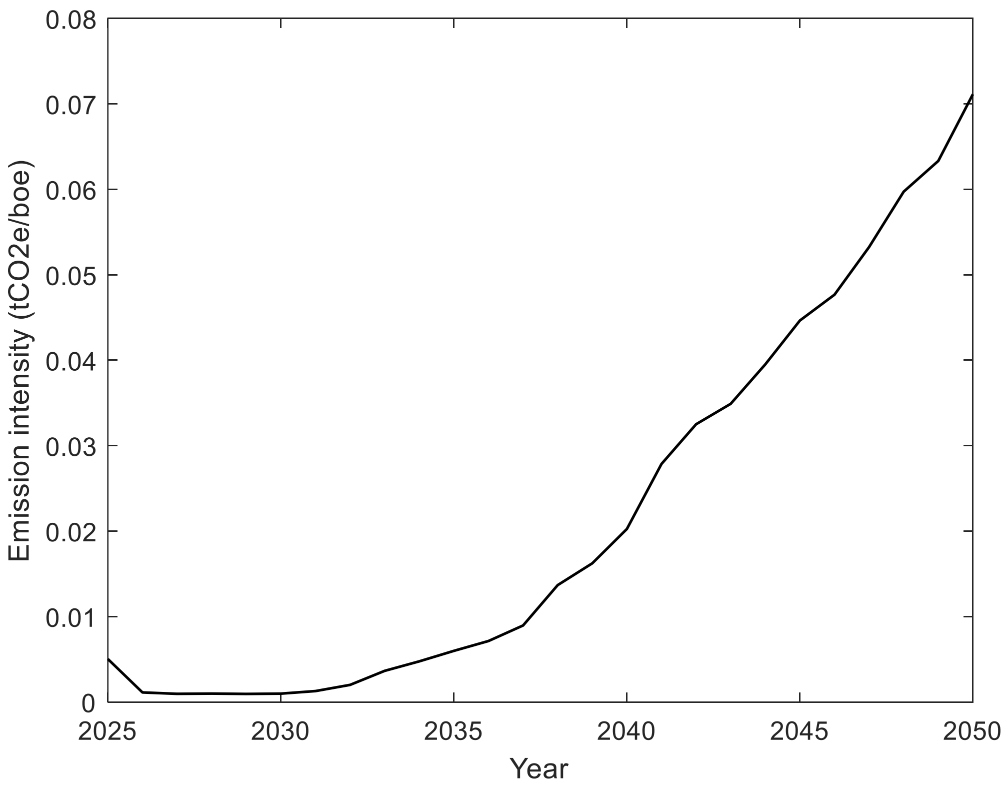
[10] 1 mmscf of natural gas converts to 0.000167 mmboe (BP, 2021)

Figure 3: Estimates of Cambo field oil and gas production profiles (Source: author plots using data provided in UK Government, 2021.a; SP Energy, 2021.a)



* bscf is billion standard cubic feet; ‘Total reserves’ is sum of oil and gas reserves, converted to mmboe

Figure 4: Annual carbon emission intensity of the Cambo field (Source: author plots using data provided in UK Government, 2021.a; SP Energy, 2021.a)



Note that the oil and gas production profiles shown in Figure 3 are exogenous to our model (i.e. see q_t^{oil} and q_t^{gas} in equations (2) – (5)). They are used to constrain their endogenous equivalents (i.e. see x_t^{oil} and x_t^{oil} in the same equations). The endogenous equivalents are responsive to price movements within the model. The carbon intensity profile shown in Figure 4 is also exogenous to our model (i.e. see δ_t^{crbn} in equation (15)) and is used in the calculation of carbon emission costs.

3.2 Expenditure data

Following Abdul-Salam et al. (2021), we use data on the unit development expenditures of fields in the west of Shetland Island region of the UKCS to calculate the total development expenditure of the Cambo field. We assume a unit development expenditure of $7.94/boe so that the total development expenditure of the Cambo field is $1.81 billion. We assume that field development expenditures are equally staggered between 2022 to 2024 (i.e. 3 years) when actual development is planned to be carried out on the Cambo field if the currently pending application for consent from the UK Government is granted. Also following Abdul-Salam et al. (2021), Abdul-Salam (2022), OGA (2018.b) and OGUK (2020), we assume that the annual operating expenditure of the Cambo field is 10% of the field development expenditure, which amounts to about $181.21 million per annum. Finally, following Abdul-Salam (2022), OGA (2018.b) and OGUK (2020), we assume that the field decommissioning expenditure is about 4% of its development expenditure, which amounts to $72.48 million to be incurred in the terminal operation period.

3.3 Prices data

We use BP revised long-term price assumptions as published in its annual report for 2020 (BP, 2020; see page 28). BP indicates that it uses these price assumptions for its investment appraisal purposes hence making these prices a credible benchmark for assessing the economic viability of the Cambo field. The price assumptions take into consideration the impact of COVID-19 on the energy landscape. In particular, it accounts for the likely acceleration of the pace of energy transition in a post-COVID energy environment. It also accounts for the likely periods of market volatility in the near term, which is thought to be likely characterised by recovery in petroleum demand but against a backdrop of reduced upstream investments and the consequent reductions in petroleum supply.

Table 1: Price assumptions (Source: BP, 2020; see page 28)

Prices	Period		
	2025 – 2029	2030 – 2039	2040 – 2050
Equilibrium oil price, p_{eqm} ($/bbl)	50	60	60
Gas price, P_t^{gas} ($/mmbtu)	3	3	3
Carbon price, P_t^{crbn} ($/t$CO_2$e)	50	100	200

* Oil price is based on Brent crude oil; gas price is based on Henry Hub gas; all prices are in real terms

As previously indicated, we assume the mean reverting oil price process shown in equation (24). To calibrate this process, we draw empirical parameters from Abdul-Salam (2022). Accordingly, we use a long-run oil price reversion speed ρ of 0.5 (unitless) and a long-run oil price volatility σ of \$16/bbl. The equilibrium oil prices for each period p_{eqm} are as shown in Table *1*.[11] To calibrate the triangularly distributed gas and carbon prices, we consider the data provided in Table *1* to be the modes of the distributions, with the minimum and maximums being 10% lower and 10% higher than the modal figures respectively. For example, the minimum, modal and maximum figures for the triangular distribution of carbon prices for the period 2030 – 2039 are \$90/tCO_2e, \$100/tCO_2e and \$110/tCO_2e respectively.

3.4 Other data

Other model data and sources are summarised in Table 2 below.

Table 2: Other model data

Parameter	**Values**	**Source**
Ring Fence Corporation Tax, %	30	UK Government, 2019.b
Supplementary Charge, %	10	UK Government, 2019.c
Investment Allowance for Supplementary Charge, %	62.50	UK Government, 2019.d
Real discount rate, %	10	Abdul-Salam et al. (2021); Abdul-Salam (2022)

4 Results and Discussion

4.1 Economic viability

Table 3 summarises our results for the economic viability of the Cambo field. With regards the NPV metric, the results show that the expected NPV of the field is \$1309.118 million, with the lower and upper 95% confidence interval levels being \$1300.819 million and \$1317.418 million respectively. NPVs of up to \$3055.692 million are achievable under particularly favourable oil, gas and carbon price realisations whilst NPVs of only up to \$320.419 million are achievable under otherwise unfavourable price environments. With regards the NPVI index metric, results show a lower and upper 95% confidence interval levels of 0.787 and 0.797 respectively, with the expected realisation being 0.792. These are considerably higher than the OGA stipulated and industry typical minimum benchmark requirement of 0.3 for an economically viable project in the UKCS. These results show that the Cambo field exceeds the economic viability threshold to a significant degree. Finally, with regards the IRR metric, the results show a lower and upper 95% confidence interval levels of 20.630% and 20.748% respectively, which are also above the typical (weighted average) cost of capital for operators, and the generally stipulated minimum IRR benchmark requirement of 15% for economically viable projects in the UKCS. A graphical illustration of the distribution of the various metrics (NPV, NPVI index, IRR) is shown in Figure 5. From the investor perspective, the results

[11] Unrealistically low values are occasionally yielded in the mean reversion oil price process and so a minimum of \$40/bbl is stipulated for each period.

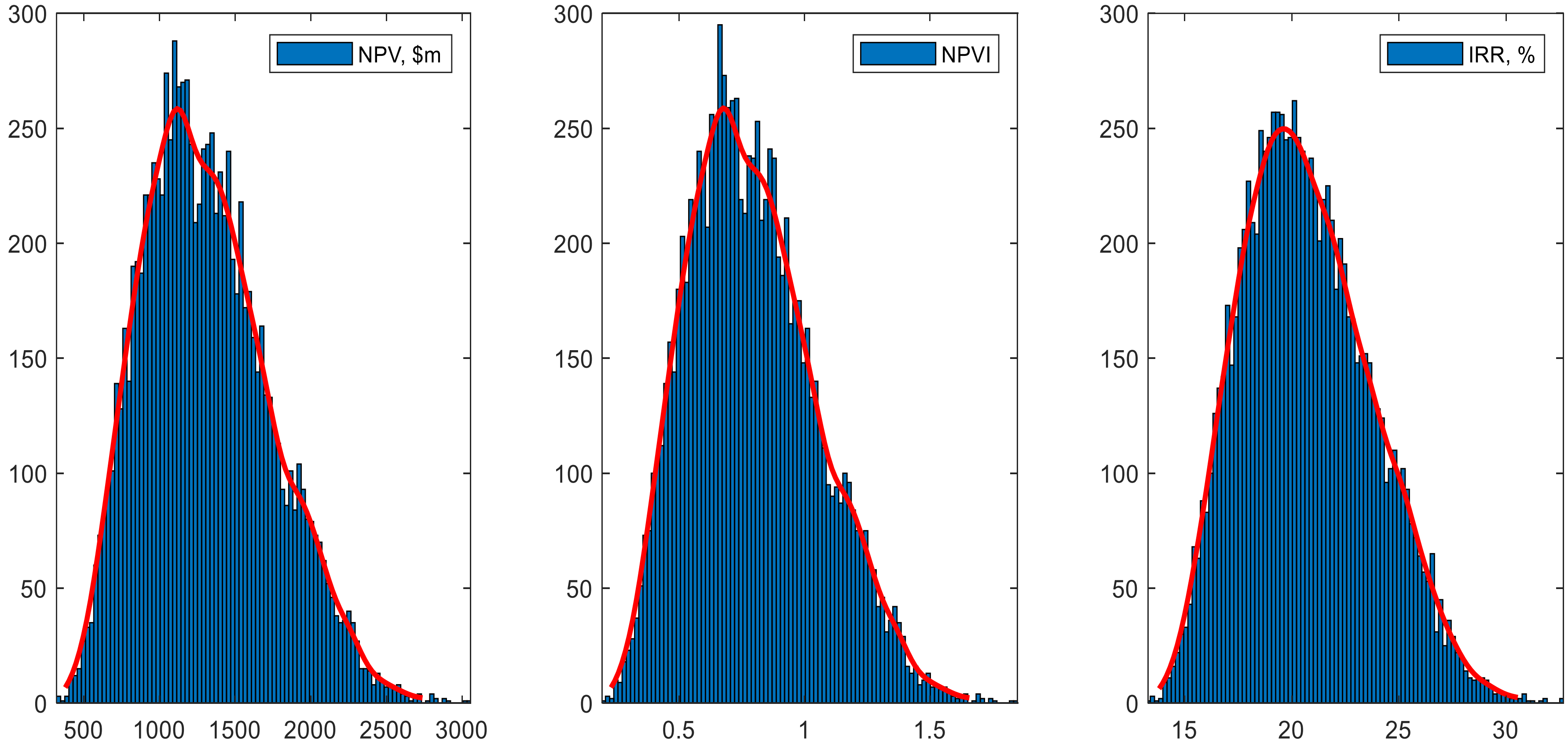
indicate that the Cambo field is inherently commercially viable and should progress to development and production. From the perspective of the UK Government, the results show that about $1119.418 million in taxes and $27.923 million in carbon charges can be expected to accrue to the UK Treasury over the lifetime of the field.

Table 3: Results indicating the economic viability of the Cambo field

Indicator	Investor			UK Government	
	NPV, $m	NPVI index	IRR, %	Tax, $m	Emission charges, $m
Minimum	320.419	0.194	13.290	721.814	15.703
Mean (expected)	1309.118	0.792	20.689	1119.418	27.923
Maximum	3055.692	1.849	32.674	2108.663	36.884
95% CI: LCL	1300.819	0.787	20.630	1115.857	27.810
95% CI: UCL	1317.418	0.797	20.748	1122.979	28.036

* CI is Confidence Interval; LCL is lower confidence level; UCL is upper confidence level
* Results generated over 10,000 Monte Carlo price simulations

Figure 5: Results of the distributions of the three investment metrics indicating the economic viability of the Cambo field



4.2 Carbon intensity and carbon leakage

As previously indicated, the UK net-zero-consistent oil and gas demand and production projections, as produced by the UK Committee on Climate Change shows that over the next few decades, UK net-zero-consistent petroleum demand outstrips projected domestic production, with UK petroleum import dependency remaining at about 50% in that period (see Figure 2). The projected UK production by the committee includes domestic production from the Cambo field. Opposers of the Cambo field have argued that development of the field is inconsistent with the UK's net-zero targets. The projections by the climate change committee however shows that this concern lacks merit as expected production from the Cambo field is included in the committee's net-zero consistent projections. In other words, expected production of oil and gas from the Cambo field is accounted for in the current UK net-zero targets.

An additional concern raised by opposers of the Cambo field is that development of the field would contribute significantly to UK and global carbon emissions. Recognising the UK Committee on Climate Change projections that the UK would need oil and gas resource towards the transition to net-zero however, the issue that would arise with regards to concerns by opposers of the Cambo field in relation to carbon emissions would be about the relative carbon intensity of the Cambo field petroleum to that of UK petroleum imports.

In that regard, the total recoverable oil and gas resource from the Cambo field is 228.22 mmboe. The total carbon emission associated with the production of this resource is 2089 ktCO_2e, resulting in an expected Cambo field carbon intensity of 9.15 kgCO_2e/boe. Table *4* presents data showing the major countries from which the UK imported crude oil over the last five years (excluding 2021). The data shows that a significant amount of UK crude oil imports is from Norway, followed by varying amounts from several other countries including Nigeria, Russia, Saudi Arabia and so on. Figure 6 shows the upstream carbon intensity of several crude oil grades from these countries. The data shows that the carbon intensity of the Cambo field is significantly lower than that of all the crude oil grades from countries where the UK imports crude oil. More broadly, Rystad Energy (2022) reports the global upstream carbon intensity of crude oil production as ranging from 5 kgCO_2e/boe to well over 100 kgCO_2e/boe, with the average being 17 kgCO_2e. The carbon intensity of the Cambo field being 9.15 kgCO_2e is well at the lower end of this range, making the field significantly carbon efficient relative to global levels. From the UK Government perspective therefore, it is prudent to provide consent for the development of the Cambo field. Failure to grant consent would imply increased UK petroleum imports from countries and provinces with higher upstream carbon intensity. This would result the carbon leakage situation which ultimately leads to greater UK contribution to global emission levels.

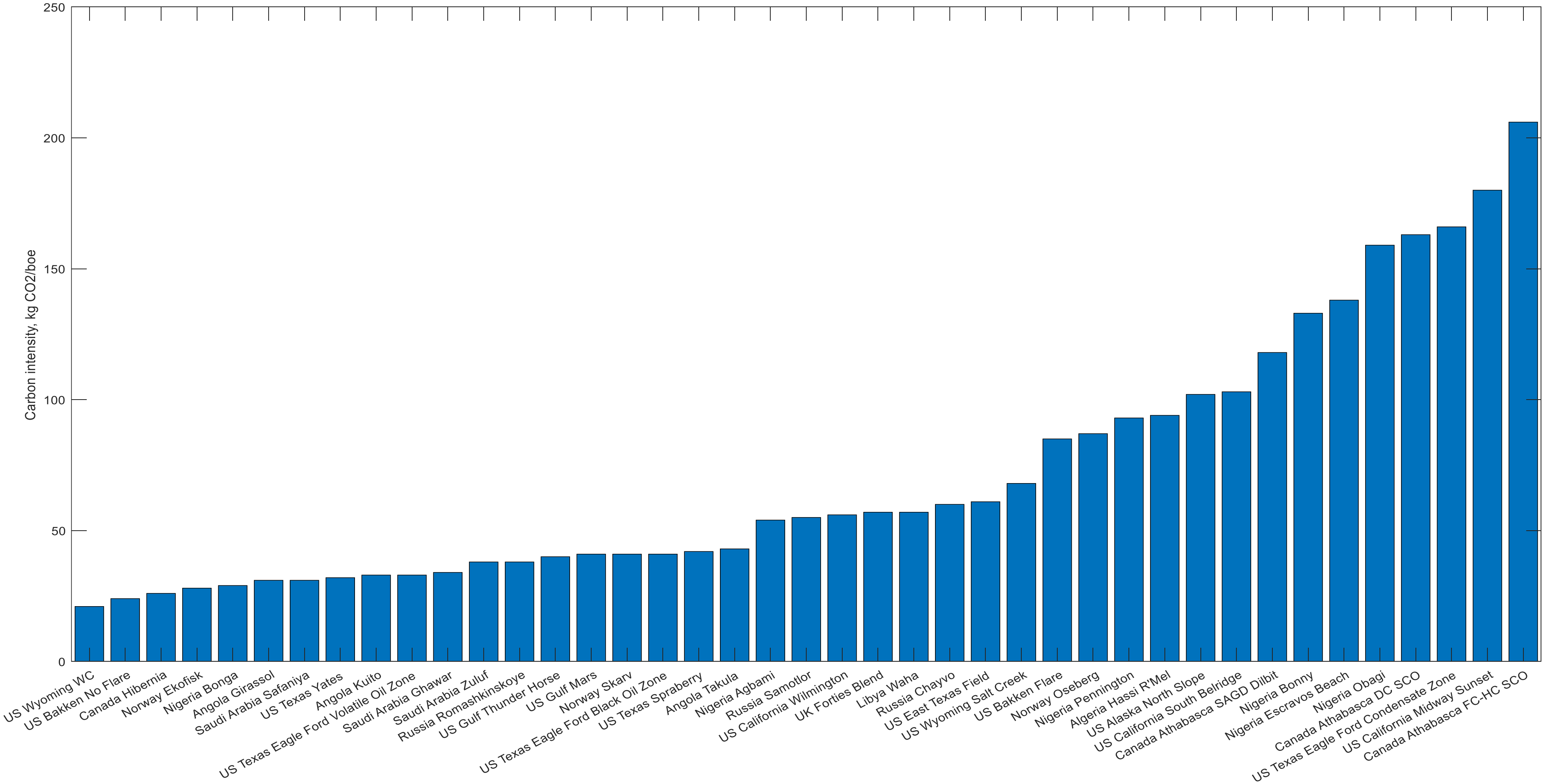
Table 4: UK crude oil imports for the period 2016 – 2020, million tonnes (percent).

Country	Year				
	2016	2017	2018	2019	2020
Algeria	2.35 (5.43%)	3.97 (7.89%)	4.75 (9.88%)	4.46 (8.93%)	1.34 (3.93%)
Angola	1.04 (2.40%)				
Canada	1.15 (2.65%)		1.66 (3.46%)	1.19 (2.39%)	1.63 (4.77%)
Libya	0.98 (2.26%)	2.71 (5.38%)	1.51 (3.13%)		
Nigeria	3.03 (7.00%)	3.88 (7.71%)	5.48 (11.40%)	3.08 (6.17%)	2.91 (8.55%)
Norway	27.91 (64.42%)	29.00 (57.59%)	22.54 (46.90%)	22.99 (46.04%)	21.95 (64.40%)
Russian Federation	2.58 (5.95%)	2.98 (5.91%)	2.33 (4.84%)	3.88 (7.78%)	3.82 (11.20%)
Saudi Arabia	1.29 (2.97%)	1.88 (3.74%)	1.14 (2.36%)		
USA		4.01 (7.97%)	7.00 (14.57%)	11.30 (22.63%)	
Rest of the World	3.00 (6.92%)	1.91 (3.80%)	1.66 (3.45%)	3.02 (6.05%)	2.44 (7.15%)

* Unbracketed data is quantity of imports in million tonnes. Bracketed data is the total proportion (%) of UK imports from a country for the relevant year

* Source: Author processing of data downloaded from UN Comtrade, 2022

Figure 6: Upstream carbon intensity of crude oil grades in countries from which the UK imports crude. (Source: Author plot using data from OCI, 2022)



5 Conclusion

The Cambo field currently symbolises the battleground for the debate on the future political economy of the UKCS in the context of decarbonisation, climate change mitigation and energy transition. The controversy surrounding the field has engendered much discussion in the UK and has generated much global interest.

This paper examined the economic viability of the Cambo field, finding that the field is inherently economically viable as per the established benchmark requirements for three commonly used investment metrics. These are the NPV, the NPVI index and the IRR metrics, which had expected values of $1.31 billion, 0.792 (unitless) and 20.689% respectively. The yielded expected values for the three metrics are substantially greater than the minimum required for a viable field in the UKCS. From the perspective of the Cambo field investors therefore, the field is a viable commercial proposition and should be sanctioned for development and production.

This paper also established that the carbon intensity of petroleum production from the Cambo field would be amongst the lowest in the world. From the perspective of the UK Government therefore, we recommend on the basis of the findings of this paper that given the high economic viability of the field and its low carbon intensity, consent to develop should be granted contingent on a stringent carbon emissions reduction programme for the field being implemented. Failure to approve the development of the field may have a number of adverse implications for the UK. First, UK reliance on petroleum imports may increase to substitute for the foregone domestic production from the Cambo field. This diminishes UK energy security. It also raises the carbon leakage spectre which arises when such petroleum imports are from countries where less meaningful attempts are being made at mitigating emissions from upstream petroleum operations. In this case, the UK would be deemed to be effectively 'offshoring' emissions to other parts of the world where upstream operations have higher carbon intensity. This situation undermines the UK's contributions to global emissions reduction targets. Second, it is worth underscoring the importance of the Cambo field and the wider UKCS sector to the UK economy. It is estimated for example that the Cambo field could sustain 1000 direct jobs, and thousands more indirect and induced jobs across the UK economy. The wider upstream petroleum UKCS sector currently sustains about 0.6% – 0.7% of all jobs in the UK,[12] underscoring its importance to the UK economy. Failure to approve the Cambo field would be akin to market signalling to investors that the UKCS is a hostile investment environment, thereby undermining the competitiveness of the province as a destination for upstream petroleum investments. This would have adverse implications for the volume and sustenance of many high-skill and high-paying UK jobs which are extensively linked to the UKCS province. Third, failure to approve the consent application to develop would mean the UK Government foregoes an expected $1.12 billion in tax revenues and $27.923 million in carbon emission charge revenues accruable from the Cambo field to the UK Treasury.

We further argue that a 'cliff-edge' energy transition stance, which calls for a complete and immediate cessation of the development of all new fields in the UKCS, would not be in the best interest of the province and the wider UK economy. We argue that a more nuanced 'just' approach to energy transition be adopted in the UKCS so that development of new

[12] See OGUK, 2021.c.

economically viable fields progresses in the province whilst at the same time taking steps to significantly reduce upstream emissions from those fields. This approach is also consistent with the UK North Sea Transition Deal agreement,[13] the UK MER strategy, and the strategy of comparable nations such as Norway and Canada. Norway for example continues to develop new fields but have recently announced a significant hike on upstream carbon emission charges in an effort to encourage reductions in upstream emissions. A carbon charge of about \$250/tCO_2e by 2030 was announced, which effectively quadruples the pre-existing level of only \$58/tCO_2e (Wood Mackenzie, 2021).

In addition, whilst the UN IPCC and IEA suggest that for the world as a whole, plans for development of new petroleum fields would need to be curtailed to meet climate change targets, this may not apply to a major petroleum net-import country such as the UK.[14] As the OGA and the UK Committee on Climate Change projections in Figure 2 show, UK net-zero-consistent oil and gas demand far outstrips UK baseline production targets over the next several decades. It is worth noting that expected oil and gas production from the Cambo field have been included in these net-zero consistent projections. It is in the interest of the UK therefore to maintain the competitiveness of the UKCS and to produce domestic reserves in order to enhance UK energy security, reduce petroleum import dependency and minimise the risk of carbon leakage to jurisdictions with less stringent and less meaningful decarbonisation goals and enforcements. To meet global climate change targets, increased UK domestic production may induce reduced production and increased stranded assets in major net-export countries.

Finally, the Cambo field contains significant reserves of natural gas. The recent natural gas energy crisis across the globe has shown the importance of UK domestic natural gas production in supplementing renewables (e.g. wind, solar), highlighting the need to consider natural gas as a complement transition fuel in the drive towards energy transition and a net-zero energy landscape.

[13] See OGUK, 2021.a
[14] The Cambo field represents only 0.68% of new volumes of reserves approved globally in 2021.

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