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Victoria Subsea Infrastructure Decommissioning Comparative Assessment Report

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ABBREVIATIONS

Abbreviation	Meaning
BEIS	Department for Business, Energy and Industrial Strategy
CA	Comparative Assessment
COP	Cessation Of Production
CO_2	Carbon Dioxide
DECC	Department for Energy and Climate Change (currently BEIS)
DP	Decommissioning Programme
DSV	Dive Support Vessel
ES	Environmental Statement
EUNIS	European Nature Information Service
GJ	Giga Joules
ICES	International Council for the Exploration of the Sea
IoP	Institute of Petroleum
km	kilometres
LAT	Lowest Astronomical Tide
m	metres
MCZ	Marine Conservation Zone
MeOH	Methanol
PSV	Platform Support Vessel
SAC	Special Area of Conservation
SCI	Site of Community Importance
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
WoW	Wait on Weather

EXECUTIVE SUMMARY

Verus Petroleum (Verus) undertook a Comparative Assessment (CA) of the technically feasible decommissioning options for the subsea infrastructure included in the Victoria Subsea infrastructure Decommissioning Project. In 2019 Verus Petroleum underwent a name change to become NEO Energy. NEO accepts, agrees and supports previous studies and assessments carried out by Verus.

The infrastructure covered by this CA includes:

- 6" gas export pipeline; and
- 3" control and chemical umbilical

The CA provides a framework for assessing the proposed decommissioning methods and assigning scores to five main criteria, further divided into the following eight sub-criteria:

1. Technical Feasibility – technical risk, ease of recovery from excursion.
2. Safety
- Qualitative assessment – risk to other users of the sea during and post operations, risk to personnel, level of diving intervention.
3. Environmental
- Environmental risk – chemical discharges, hydrocarbon discharge, seabed disturbance, estimated discard to sea, estimated discard to landfill;
- Energy use;
- Atmospheric emissions.
4. Societal – commercial fisheries, other offshore users, onshore communities and legacy issues.
5. Economic – cost estimation for each option.

Scoring is based on the BMT Cordah CA Methodology and the BEIS Guidance Notes, with the approach for each assessed criterion detailed within Appendices B to F. Where appropriate, qualitative and quantitative descriptors were used to score each of the aspects within the criteria/ sub-criteria. NEO's Risk Matrix was used to provide scores between 1 (low risk) and 25 (high risk). Scores were totalled to provide an overall assessment scoring for the criteria/ sub-criteria. A weighting, as defined by NEO to allow direct comparisons between the criteria for each decommissioning option. This enabled a balanced and transparent comparison, to identify a preferred method for decommissioning of the Victoria subsea infrastructure.

Suitability of the decommissioning options was initially evaluated based on the availability of proven technologies and the recoverability, should there be a deviation from the planned activities being carried out.

Further to initial submission of this report, 2021 survey results have shown that the impact of ongoing sand wave migration has resulted in a pipeline exposure which will only worsen over time. Additionally, it is predicted that other pipe / umbilical exposures will occur as the two most easterly sand waves continue to move westwards. On this basis it is now proposed that 100m+ sections of "at risk" pipe and umbilical be removed from within each of these two sand wave profiles.

The five pipeline and umbilical decommissioning options selected for further assessment through the CA process were:

- Option P1 - full removal of all seabed infrastructure (cut and remove and recover pipeline, reel umbilical back on vessel);
- Option P2a - partial removal of the seabed infrastructure (cut and remove and recover pipeline ends plus midline and AR pipeline crossing sections, reel back umbilical);
- Option P2b - partial removal of the seabed infrastructure (cut and remove and recover pipeline ends plus midline pipeline sections, reel back umbilical);
- Option P3a - leave in situ (cut, remove and recover only pipeline / umbilical ends and midline sections);
- Option P3b – leave in situ (cut, remove and recover only pipeline / umbilical ends, midline sections and AR pipeline crossing section).

It should be noted that the above midline sections relate to those 100m+ lengths of pipeline and umbilical requiring to be removed to mitigate against future exposure from the effect of sand wave migration.

In addition, NEO have also considered the comparison of potential flushing options for flooding/ degassing the pipeline prior to decommissioning.

The six flushing options for the Victoria pipeline taken forward for further assessment through the CA process were:

- Option F1 – using a dive support vessel (DSV) flush from the Viking BD skid through to the tree and directly re-inject fluids (gas and condensate) downhole into the well, when the rig is on location;
- Option F2 – using a DSV flush from the Viking BD skid through the tree and onto the rig via the workover riser. Gas will be vented on the rig and fluids collected for disposal onshore;
- Option F3 – using a DSV flush from the Viking BD skid through to the Victoria valve skid and onto the rig via a separate flowline spool from the rig. Gas will be vented on the rig and fluids collected for disposal onshore;
- Option F4 – using a DSV flush from the Viking BD skid through to the Victoria valve skid and then into a separate collection vessel/ platform support vessel (PSV). Gas is vented on the PSV and fluids collected for disposal onshore;
- Option F5 – use a single vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea;
- Option F6 – use one vessel to open valves to allow free flooding of the pipeline, no flushing.

Tables 1 and **2** provide the scored results for each assessment and the total CA score (out of a maximum of 100 points) for each of the pipeline decommissioning and flushing options, respectively. The decommissioning option with the highest normalised/ weighted score represents the best/ preferred option.

The CA concluded that Option P3a, leave pipeline and umbilical in situ with removal of pipeline ends and midline exposed sections, is the preferred option for decommissioning of Victoria pipeline and umbilical due to high scores against majority of criteria. This option has markedly lower requirements for subsea intervention, lower risk to the decommissioning workforce offshore and associated transport on land (Safety), lowest impact to environmental receptors (Environmental Risk), lowest energy and atmospheric emissions due to lower vessel time and onshore requirements (Energy use and Atmospheric Emissions), lowest risk of snagging or loss of fishing gear (Societal) and was least expensive option (Economic).

Of the technically feasible pipeline flushing options, Option F5, is the preferred option This option uses a vessel to vent the pipeline to sea at the Victoria valve manifold, allowing free flood from Victoria. This is then followed by relocation of the vessel to Viking BD skid and flushing the remaining contents to sea. Though it is the second-best scoring option, it was selected due to potential safety concerns to divers during decommissioning activities from gas that may be trapped in the pipeline (a maximum volume of 375 m^3, assuming subsea temperature of 4°C).

Table 1: Summary table of the comparative assessment weighted scores/ results for pipeline decommissioning options

Option	Comparative Assessment scores					Total Comparative Assessment score
	Technical feasibility	Safety	Environmental	Societal	Economic	
P1. Full removal (subsea cut and lift of pipeline; umbilical reeled onto a vessel)	15	20	12.2	10	12.8	**70.0**
P2a. Partial removal (ends and crossing removed, umbilical removed)	20	20	14.9	7.3	16.1	**78.3**
P2b. Partial removal (ends removed, umbilical removed)	16.7	27.3	15.2	7.3	16.9	**83.4**
P3a. Leave in situ (ends removed with remediation where required)	16.7	30	20	10	20	**96.7**
P3b. Leave in situ (ends and crossing removed)	20	27.3	18	10	19.1	**94.4**

Table 2: Summary table of the comparative assessment weighted scores/ results for flushing options

Option	Comparative Assessment scores					**Total Comparative Assessment score**
	Technical feasibility	Safety	Environmental	Societal	Economic	
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	8.3	30.0	16.8	10.0	12.0	**77.1**
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	15.0	22.9	12.4	6.3	8.5	**65.1**
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	15.0	22.9	12.4	6.3	9.7	**66.3**
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	15.0	22.9	15.0	6.3	9.1	**68.3**
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	20.0	26.7	14.3	10.0	17.1	**88.1**
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	20.0	26.7	15.7	10.0	20.0	**92.4**

1.0 INTRODUCTION

This report describes the outcome of the Comparative Assessment (CA) carried out by NEO as part of the Victoria Subsea Infrastructure Decommissioning Project, to assess the technically feasible decommissioning options for the Victoria subsea infrastructure.

1.1 Field Overview

The Victoria gas field lies in the UKCS Block 49/17 in the southern North Sea, with the water depth along the pipeline varying between 21 to 27 m Lowest Astronomical Tide (LAT).

The existing Victoria subsea infrastructure is a tie-back to the Harbour Energy owned Viking BD skid, presented in the diagram in **Figure 1.1**. Production from Victoria commenced in October 2008, with gas being exported to the Theddlethorpe terminal via the Harbour Energy operated Viking B complex.

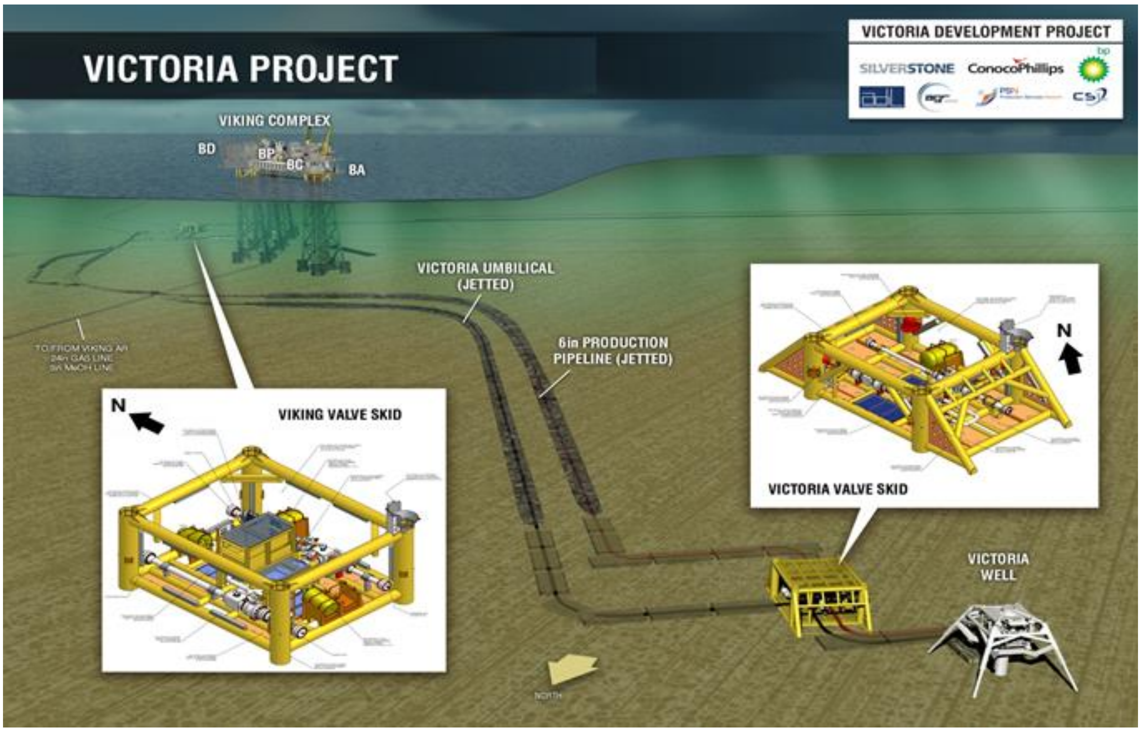


Figure 1.1: Victoria field diagram

The Victoria subsea system consists of:

- One subsea production well complete with protective structure;
- One production gas flowline;
- One subsea umbilical designed to provide hydraulic control, electrical signal and chemical injection cores;
- Spools for Victoria development (of similar construction as the pipeline), totalling approximately 177 m:
    - Victoria tree to Victoria valve skid, approximately 27 m;

  - Victoria valve skid to production pipeline, approximately 72 m, split into two sections;
  - Production pipeline to Viking DB valve skid, approximately 78 m, split into three sections.
- Two pipeline end valve skids (one at Victoria field location and one adjacent to the Viking BD platform location) to provide flowline isolations, tie-in points, and control tie-ins (both structures are piled);
- Single subsea gas meter located on the Victoria skid;
- 150 (total) concrete mattresses – 60 at Victoria well location, 45 at the pipeline crossing of Viking BD to AR pipeline and 45 at the Viking BD skid location adjacent to the Viking BD platform;
- 13 frond mattresses surrounding the Victoria well head; and
- An estimated 242 grout bags used in the construction of crossing over Viking AR 24" and 3" lines, and to support the swan neck spools at the valve skids.

The Cessation of Production (COP) was approved in January 2016.

1.2 Infrastructure within the Scope of this CA

The CA covers the technically feasible decommissioning options for the Victoria pipeline PL2526 and umbilical PLU2527 from the Victoria well to Viking BD valve skid.

1.2.1 Pipelines

Two pipelines connect the Victoria well and Viking BD platform:

- 6" gas export pipeline (PL2526); and
- 3" control and chemical umbilical (PLU2527).

Both pipelines were installed in 2008. The 3" control and chemical umbilical and the 6" gas export pipeline are trenched and buried in separate trenches. **Table 1.2** provides detail of the two pipelines.

Table 1.2: Victoria pipelines

Type	NB Diameter (")	Outside diameter (mm)	Length (km)	From/ To	Composition	Condition
PL2526 Gas export	6	165	3.80	Victoria valve skid to Viking BD valve skid	X65 carbon steel 12.7 mm wall thickness, with 2.5 mm 3LPP anti-corrosion coating	Trenched and buried
PLU2527 Umbilical	3	108	3.95	Viking BD valve skid to Victoria valve skid	12 mm black longitudinal stripe, outer PP roving on a bitumen bedding, 3.15 diameter steel armour wires, inner PP roving, 17 cores	

The umbilical (**Figure 1.2**) holds the following content:

- Two cores of methanol and corrosion inhibitor mixture. A total volume of 1,000 litres MeOH (MI Swaco), 0.5 litres corrosion inhibitor (KI5351).
- Four cores of hydraulic fluid. Total volume of 1,560 litres (Aqualink 300E).
- Two cores of hydraulic fluid – spare. Total volume of 780 litres (Aqualink 300F).
- Two cores of deionised water and dye – spare. Total volume of 1000 litres.

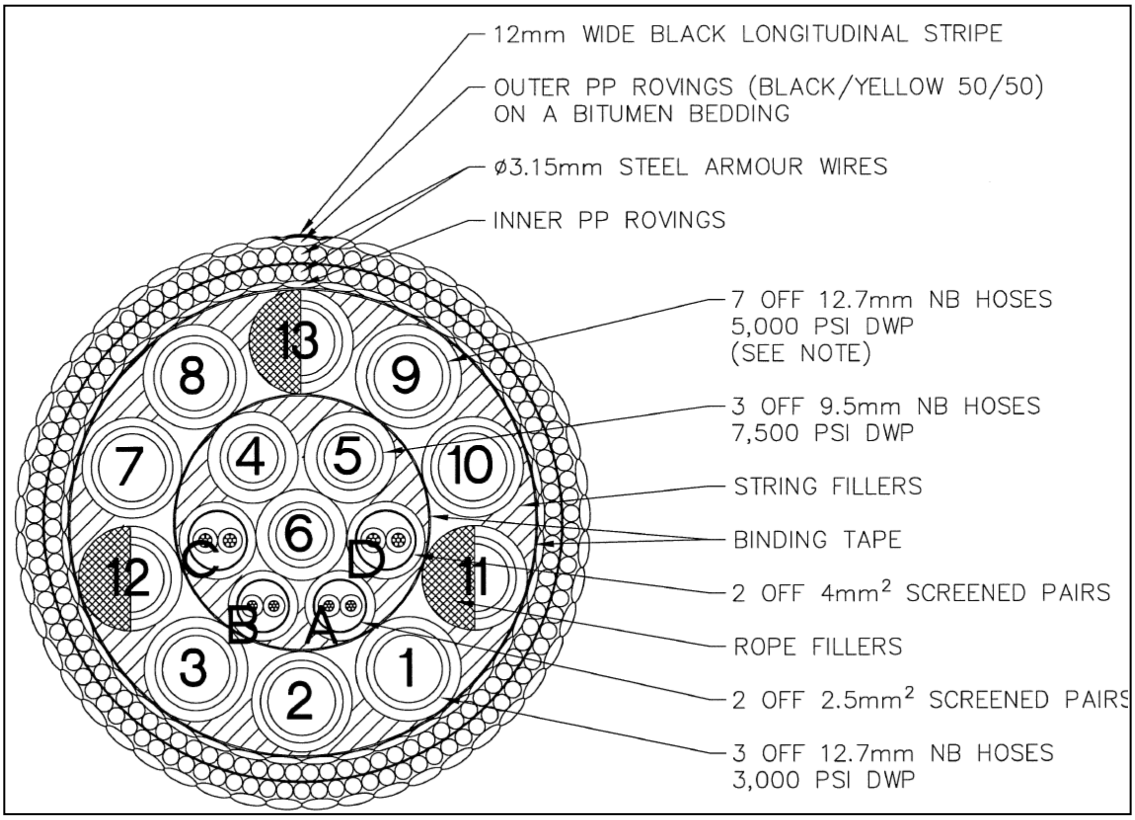


Figure 1.2: Control and chemical injection umbilical cross section

1.3 Infrastructure and Materials not within this CA

In accordance with the 2018 BEIS Decommissioning Guidance, a CA is not necessary for elements of a Decommissioning Programme (DP) involving full removal of associated structures for re-use, recycling or final disposal on land. Therefore, all of the structural components to be decommissioned in this manner can be excluded from the CA scope (e.g. spools, Victoria valve skid, mattresses). The Environmental Appraisal (EA) for the Victoria field will address all of the elements to be decommissioned.

1.4 Environmental and Societal Settings

Table 1.3 summarises the environmental and societal characteristics and sensitivities surrounding the Victoria pipelines. References used to compile Table 1.3 are listed in Appendix A.

Figure 1.3 presents the commercial fisheries data for the area from 2016. This provides an indication of where the fishing effort is concentrated in the surrounding area by the targeted species types.

Figure 1.4 illustrates the offshore conservation areas in the vicinity of the Victoria Subsea Infrastructure Decommissioning Project. There are two conservations zones overlapping the project area, the North Norfolk Sandbanks and Saturn Reef SAC (designated for protection of Annex I habitats, "Sandbanks, which are slightly covered by seawater all the time," and *Sabellaria spinulosa* reef) and the Southern North Sea candidate SAC (cSAC); designated for the protection of Annex II species harbour porpoise (**Table 1.3**).

Table 1.3: A summary of key environmental and societal characteristics and sensitivities in the decommissioning area

Aspect	Detail
Site overview	
The Victoria subsea structure to be decommissioned is located within Block 49/17 in the UK sector of the southern North Sea. Water depth along the pipeline route varies from a minimum 21 m to a maximum 27 m LAT.	
Environmental Aspects	
Conservation Interests	
Offshore and Coastal Marine Protected Areas and Annex I habitats	
North Norfolk Sandbanks and Saturn Reef SAC	Designated for: • Sandbanks, which are slightly covered by seawater all the time. These typically have fields of sand waves associated with them; • Annex I biogenic reef habitats formed by the polychaete worm (*Sabellaria spinulosa*) are also present. Victoria subsea infrastructure located within this SAC.
Southern North Sea SAC	Designated for: • Annex II species harbour porpoise (*Phocena phocena*). Victoria subsea infrastructure located within this SAC.
Haisborough, Hammond and Winterton SAC	Designated for: • Sandbanks, which are slightly covered by seawater all the time; • *S. spinulosa* reef habitats. Located 52 km southeast of the Victoria subsea infrastructure.
Dogger Bank SAC	Designated for: • Annex I sandbank slightly covered by seawater at all time. Located 88 km north of the Victoria subsea infrastructure.
Inner Dowsing, Race Bank and North Ridge SAC	Designated for: • Sandbanks, which are slightly covered by seawater all the time; • *S. spinulosa* reef habitats. Located 89 km west of the Victoria subsea infrastructure.
Greater Wash pSPA	SPA protected features: • Over wintering: Red-throated Diver, Common Scoter, Little Gull; • During breading season: Common Tern, Sandwich Tern, Little Tern. Located 69 km southwest of the Victoria subsea infrastructure.

Aspect	Detail
Cromer Shoal Chalk Beds MCZ	Protected features: • Moderate energy infralittoral rock, high energy infralittoral rock, moderate energy circalittoral rock, high energy circalittoral rock, subtidal chalk, subtidal coarse sediment, subtidal mixed sediment, subtidal sand, peat and clay exposures. Located 78 km southwest of the Victoria subsea infrastructure.
Markham's Triangle MCZ	Recommended for: • Coarse and sand sediments, interspaced with rock and gravel that provide habitat for polychaete worms, bivalve molluscs and sandeels; • Sandeels here provide a key food source for grey and harbour seals and harbour porpoise. Located 54 km north east of Victoria subsea infrastructure.
Wash Approach MCZ	Recommended for: • Carpets of bryozoans, sea squirts, hydroids, sponges and anemones, squat lobsters and crabs; • Subtidal sands and gravels. Located 81 km west of the Victoria subsea infrastructure.
Offshore and Coastal Annex II species	
Harbour porpoise	• Sightings across the Victoria area range from low to very high throughout the year. The highest abundance of harbour porpoise has been recorded during August in the quadrants surrounding the Victoria subsea infrastructure; • The Southern North Sea SAC has been designated to protect harbour porpoise. Victoria subsea infrastructure is located within this SAC; • The Markham's Triangle MCZ (54 km northeast of the Victoria subsea infrastructure) is known feeding ground for harbour porpoise.
Bottlenose dolphins	• Typically present in low abundance in the area in November, with no presence recorded throughout the rest of the year.
Grey seals	• Grey seal density along the decommissioning area ranges from 0 to 1 seals per 25 km^2; • Haul-out and breeding sites are located within the Humber Estuary SAC, more than 100 km from the decommissioning area; • The Markham's Triangle MCZ (54 km northeast of the Victoria subsea infrastructure) is known feeding ground for grey seals.
Harbour seals	• Harbour seal density along the decommissioning area ranges from 0 to 1 seals per 25 km^2; • Haul-out and breeding sites are located within The Wash and North Norfolk Coast SAC, more than 100 km from the decommissioning area; • The Markham's Triangle MCZ (54 km northeast of the Victoria subsea infrastructure) is known feeding ground for harbour seals.
Potential Conservation Interests	
Annex I sandbanks	• Within Block 49/17.
Sandeel grounds	• Within Block 49/17.
Reef points	• Located 11.8 km north west of the Victoria subsea infrastructure.

Aspect	Detail
Plankton	
Plankton in the area surrounding the Victoria subsea infrastructure is typical for the southern North Sea. Dominant phytoplankton species are dinoflagellates of the genus Ceratium, including *C. fusus*, *C. furca* and *C. tripos*. High numbers of the genus Chaetoceros are also present. The zooplankton community comprises *Calanus helgolandicus* and *C. finmarchicus* as well as *Paracalanus* spp., *Pseudocalanus* spp., *Acartia* spp., *Temora* spp. and cladocerans such as *Evadne* spp.	
Benthic environment	
Seabed sediments	Furthest offshore the seabed is predominantly circalittoral fine sand and sandy mud, with the large shallower infralittoral fine sand area of Dogger Bank in the north of the regional sea and numerous sand banks aligned parallel to the shore through much of the nearshore waters. The EUNIS classification system identifies one main Level 4 seabed habitat in block of interest: • A5.27 Deep circalittoral sand. Additionally, in Block 49/17 following habitats were recorded: • A5.25 or A5.26 - Circalittoral fine sand or circalittoral muddy sand; • A5.23 or A5.24: Infralittoral fine sand or infralittoral muddy sand; • A5.15: Deep circalittoral coarse sediment; • A5.14: Circalittoral coarse sediment.
Benthic fauna	The fauna can be described as typical for fine sand and muddy sand sediments of the southern North Sea, and may include communities consisting of polychaetes, mobile amphipods, echinoderms, molluscs and crustaceans. Species such as sandeel and plaice may also be present in these assemblages.
Socioeconomic Aspects	
Fish and shellfish – spawning and nursery areas	
Spawning areas	There are spawning areas for cod, mackerel, lemon sole, *Nephrops*, plaice, sandeels, sole, sprat and whiting within ICES rectangle 35F2.
Nursery areas	There are potential nursery areas in the ICES rectangle for cod, herring, lemon sole, mackerel, *Nephrops*, herring, horse mackerel, plaice, sandeel, sprat, tope shark and whiting within ICES rectangle 35F2. A high probability of age 0 (juveniles) horse mackerel has been reported within Block 49/17. This is considered as a high intensity nursery area for these species.
Marine Mammals	
Cetaceans	Minke whale, long-finned pilot whale, bottlenose dolphin, common dolphin, white-beaked dolphin, white-sided dolphin and harbour porpoise, have been sighted in the decommissioning area, with the most sightings occurring in the summer months. However, only white-beaked dolphin and harbour porpoise have been sighted within Quadrant 49.
Seals	Grey and harbour seals can be potentially found in both block of interest, although in very low density.
Seabirds	
The most common species of seabird found in the study area include: Fulmar, Gannet, Guillemot, Kittiwake, Razorbill, Puffin, Little Auk; as well as numerous species of gull, tern, and skua.	

Aspect	Detail
Seabird sensitivity	Very high seabird sensitivity to surface pollution has been recorded in July and low in August and September in Block 49/17. Data for the remaining months have been interpolated from neighbouring months or surrounding blocks and very between low and extremely high sensitivity (in winter months). No data are available for January, April, May and November.
Socioeconomic	
Fisheries	Commercial fisheries landings and value were recorded as low for 2016 within ICES rectangles 35F2. The annual value of catches recorded in 2016 was £366,345. In 2016 only beam trawls were used in terms of fishing gear. The relative quantity and values of fish landed from ICES rectangle 35F2 has varied through the years. Quantity of catch had historically been predominately of demersal species until 2019 when shellfish contributed slightly more by weight. Between 2015 and 2019, the total annual live weight of fish landed from 35F2 ranged from a maximum of 1,102.88 tonnes in 2017 to a low of 10.13 tonnes in 2018. The catches had a value of £2,169,216 and £20,091 respectively.
Shipping	Overall shipping density in the vicinity of the Victoria subsea infrastructure is considered very low.
Oil and gas industries	Seven wells and 22 pipelines are located within 100 m radius from the Victoria subsea infrastructure.
Offshore renewables	The closest wind export cable to the Victoria subsea infrastructure located approximately 40 km to the northwest is in the planning stage.
Aggregate activities	The closet aggregate production areas are the Humber 3 and Humber 5, located approximately 21 km northwest and 19 km north, respectively, of the Victoria subsea infrastructure.
Military activities	There is no military activity expected within 50 km of the Victoria subsea infrastructure.
Wrecks	There are four dangerous wrecks within the Block 49/17, located between 920 m and 7.1 km from the Victoria subsea infrastructure.
Telecommunications	The Tampnet telecommunication cable is located within Block 49/17, 2.6 km to the west of the Victoria subsea infrastructure.

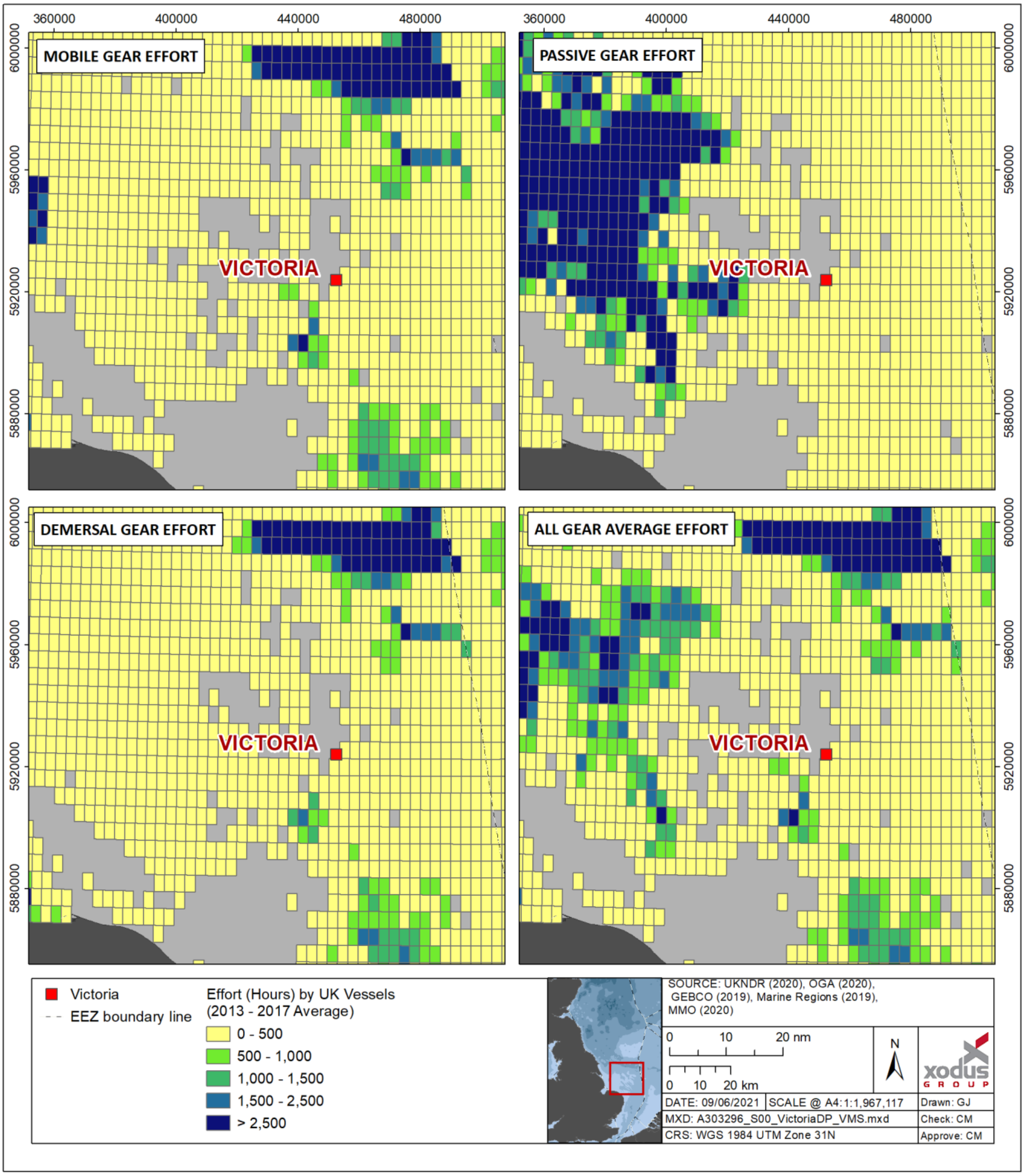


Figure 1.3: Annual average fishing effort (hours) for ICES rectangle 35F2 close to Victoria infrastructure

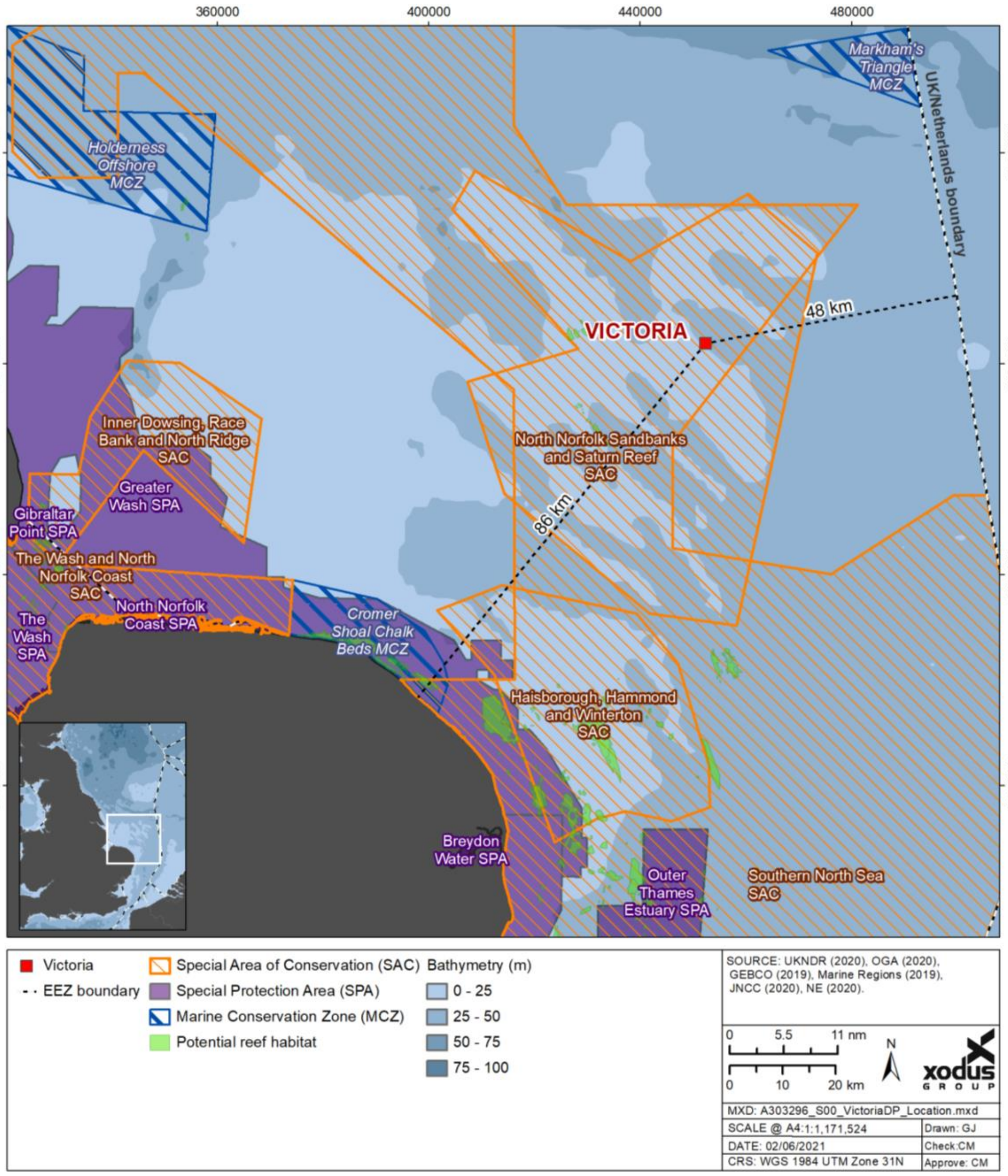


Figure 1.4: Conservation features in the vicinity of Victoria field

2.0 DECOMMISSIONING OPTIONS ASSESSED IN THE CA

NEO intends to remove the Victoria valve skid, wellhead, spools, mattresses and grout bags within the Victoria field and those NEO has responsibility for in proximity to the Viking facilities (**Figures 2.1** and **2.2**). Five options for the decommissioning of the pipeline and umbilical have been taken forward for the CA:

- **Option P1** - full removal of all seabed infrastructure. The pipeline will be removed by cut and lift and the umbilical by pulling onto a DSV fitted with a powered carousel;
- **Option P2a** - partial removal of the seabed infrastructure. The pipeline will be cut where it exits the seabed and removed (**Figures 2.1** and **2.2**). Also, approximately 150 m of pipeline will be removed at the crossing (**Figure 2.2**) and 240m of pipeline around the midline exposures (and potential future exposures) will be removed. The remaining pipeline will be left in situ. For this option, as for Option P1, NEO is proposing to remove the umbilical;
- **Option P2b** - partial removal of the seabed infrastructure. The pipeline will be cut where it exits the seabed and removed (**Figures 2.1** and **2.2**) and 240m of pipeline around the midline exposures (and potential future exposures) will be removed. The crossing (**Figure 2.2**) and the rest of remaining pipeline will be left in situ. For this option, as for Option P1, NEO is proposing to remove the umbilical;
- **Option P3a** - leave in situ. Only pipeline and umbilical ends to be removed along with the pipeline tie-in spools and any midline sections considered to be at risk of exposure from the effect of sand wave migration (240 m of the pipeline and 240 m of the umbilical. The remainder of the pipeline and umbilical will be left in situ.
- **Option P3b –** leave in situ. Pipeline and umbilical ends to be removed along with the pipeline tie-in spools and any midline sections considered to be at risk of exposure from the effect of sand wave migration (240 m of the pipeline and 240 m of the umbilical).. Also, approximately 150 m of pipeline and umbilical will be removed at the crossing (Figure 2.2). The remainder of the pipeline and umbilical will be left in situ.

For all the above options, NEO intends to remove mattresses and grout bags where found, wherever safe to do so, with the exception of the following:

- The 15 mattresses (plus grout bags) that are located over the umbilical at the Victoria end. The umbilical is buried at full trench depth with substantial sediment cover (approximately 1 m) established above the mattresses. . Applies to options P3a and P3b
- The 45 mattresses (plus grout bags) associated with protection of the Victoria pipeline and umbilical at the AR pipeline crossing. Applies to option P2b and P3a

In Options P2b and P3a pipeline crossing between Harbour Energy's AR and Victoria Pipelines and associated protective mattresses and grout bags will remain in situ. Both pipelines are out of use, with crossing currently protected by mattresses, with much of it covered by sand. Harbour Energy has been granted an approval to leave AR pipeline in situ. NEO proposes to align their Options P2b and P3a with this approach and leave crossing in situ. Harbour Energy will have to issue letter of approval if any of these options is chosen.

As outlined in the supporting EA document, the results of the 2021 pipeline burial survey show that, with just a few noted exceptions at two sandwave locations, the trenched pipeline and umbilical have adequate depth of cover to offer protection to and from fishing gear interaction and this is expected to remain the case, even when sand wave movement is taken into account. Thus, with the plan being to remove those currently "at risk" pipeline and umbilical sections within the aforementioned sandwaves, NEO will not be using rock cover as remediation for pipeline or umbilical exposures now or in the future.

In addition, NEO have also considered the comparison of potential flushing options for flooding/ degassing the pipeline prior to decommissioning.

The six flushing options for the Victoria pipeline taken forward for further assessment were:

- **Option F1** – using a DSV flush from the Viking BD skid through to the tree and directly re-inject fluids (gas and condensate) downhole into the well, when the rig is on location;
- **Option F2** – using a DSV flush from the Viking BD skid through the tree and onto the rig via the workover riser. Gas will be vented on the rig and fluids collected for disposal onshore;
- **Option F3** – using a DSV flush from the Viking BD skid through to the Victoria valve skid and onto the rig via a separate flowline spool from the rig. Gas will be vented on the rig and fluids collected for disposal onshore;
- **Option F4** – using a DSV flush from the Viking BD skid through to the Victoria valve skid and then into a separate collection vessel (PSV). Gas is vented on the PSV and fluids collected for disposal onshore;
- **Option F5 –** use a single vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea;
- **Option F6 –** use one vessel to open valves to allow free flooding of the pipeline, no flushing.

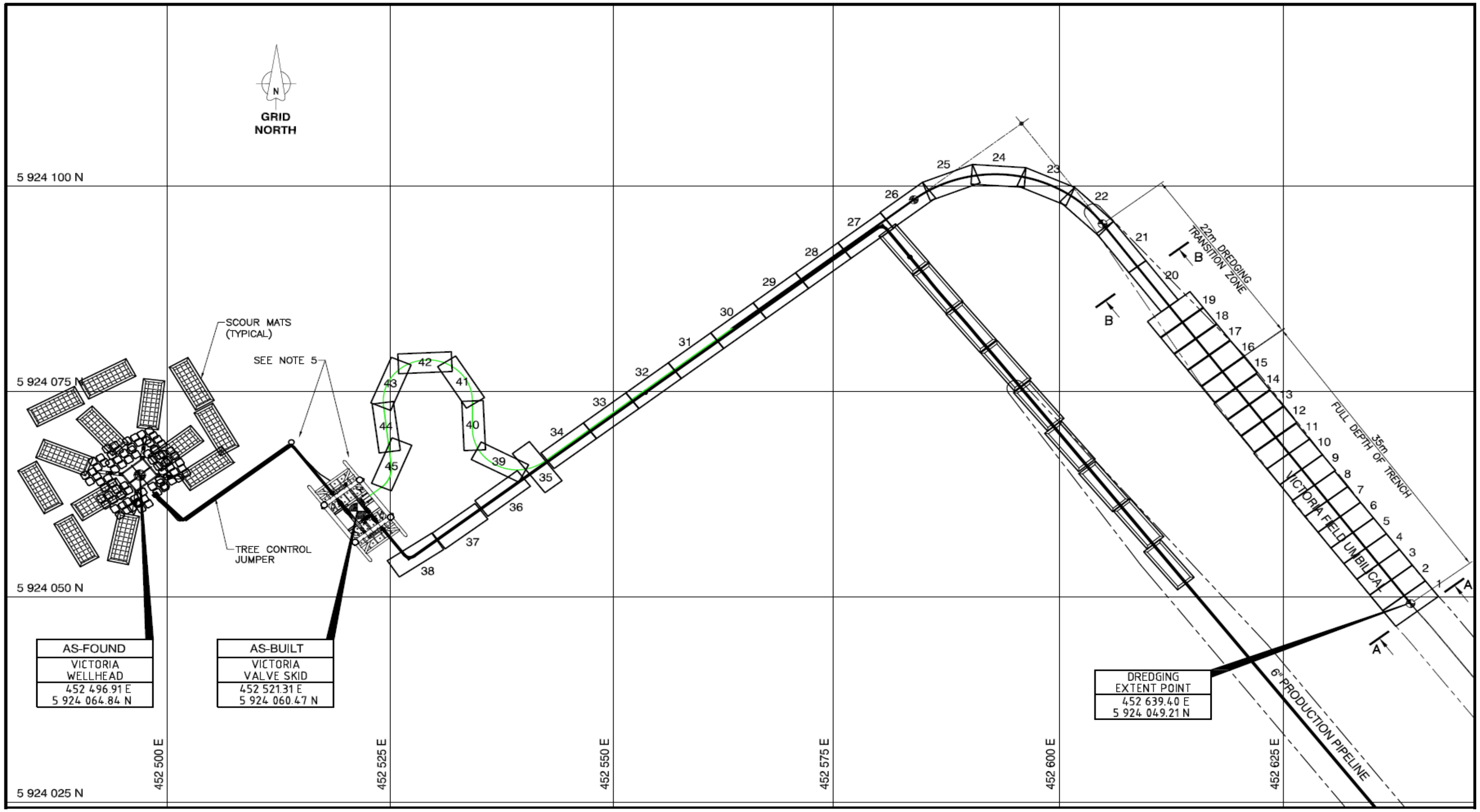


Figure 2.1: Overview of Victoria subsea infrastructure within the Victoria field

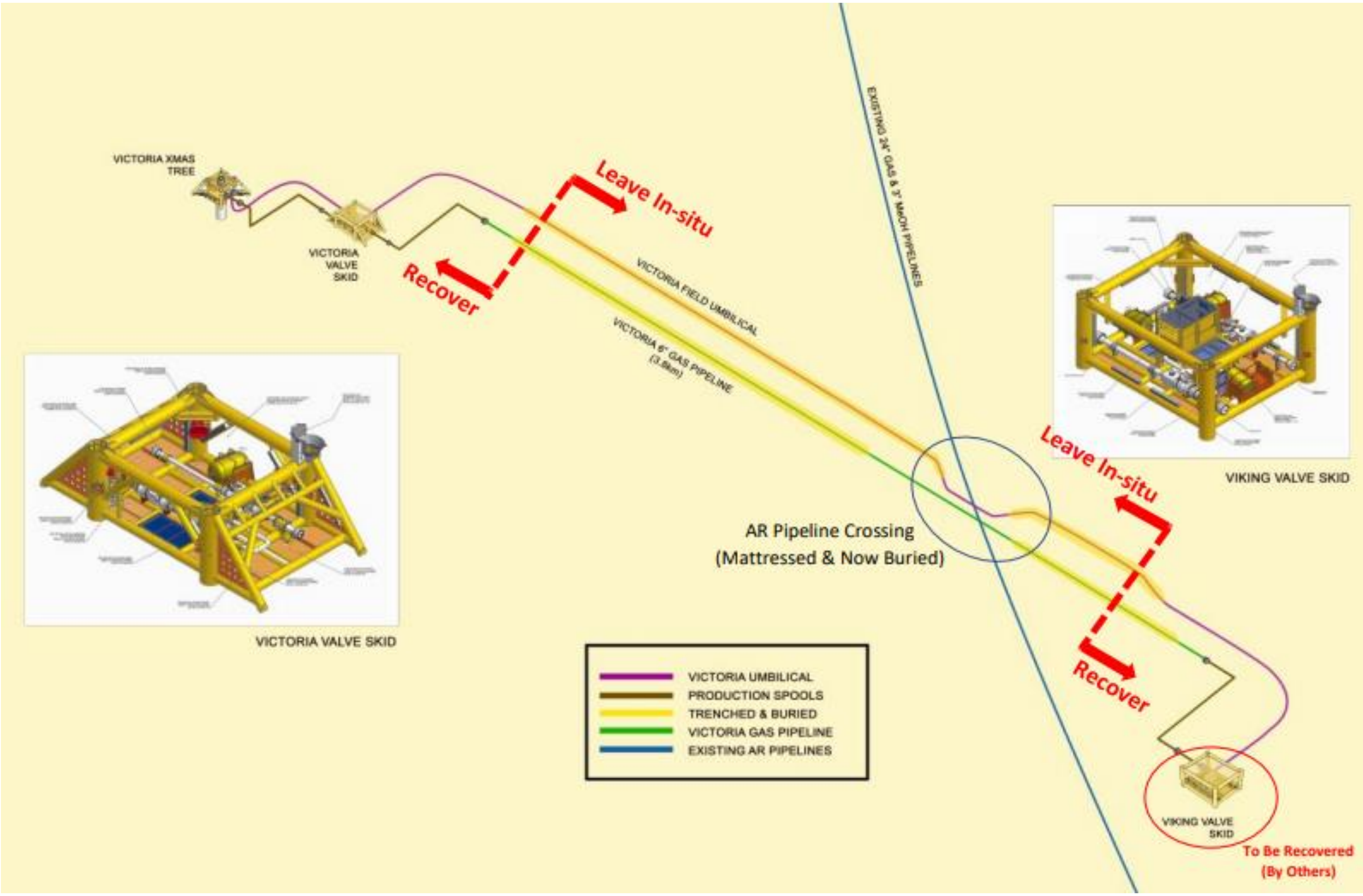


Figure 2.2: Overview of Victoria subsea infrastructure within the Viking facilities

2.1 General Assumptions

For comparative purposes, assumptions and limitations have been made in regard to scope, materials, transportation, vessel usage, etc. These general assumptions and considerations are listed below. Additional assumptions for each of the criteria evaluated in this CA are included in the description of the methodologies in the relevant Appendices.

- A monitoring programme has been accounted for in the options where infrastructure is decommissioned in situ;
- A breakdown of vessel types, tasks/ activities, durations, crewing (personnel on board), diver numbers, dive durations and contingency time for wait on weather (WoW), have been provided by NEO;
- The materials would be landed onshore at Great Yarmouth and transported to Ipswich for treatment and further disposal/ recycling;
- A return trip for each lorry (for onshore transport of waste materials) has been assessed;
- A return trip involving a helicopter flight to the Victoria Subsea Infrastructure Decommissioning area is estimated to take one hour;
- Recovered steel and anode materials from pipeline have been assumed to be recycled, where removed;
- It has been assumed for the purposes of comparison that all anode material is aluminium;
- It has been assumed that all mattresses and umbilical are going to a landfill.

3.0 CA METHODOLOGY

The following section details the CA process by which the options for decommissioning of the pipelines and flushing operations were assessed.

In preparation for the CA, NEO identified and described the decommissioning options, decided upon the assessment criteria (and sub-criteria) to be used in the CA (Section 3.2) and established the weighting to be applied to scores for the individual assessment criteria. The methods and weightings reflect the balance of NEO's decision-making priorities, corporate values and stakeholder views (Section 3.3).

The Victoria Subsea Infrastructure Decommissioning CA was carried out in compliance with the BEIS Guidance Notes using BMT Cordah Limited's (BMT Cordah) CA methodology.

3.1 CA Workshop

As part of the CA, a workshop was undertaken to assess the technical feasibility and environmental and societal risks. These were independently facilitated and chaired by BMT Cordah on 8th November 2017. Participants of the workshop included a mix of disciplines and specialists from Verus (now NEO) and BMT Cordah (**Figure 3.1**), including:

- Verus Petroleum (NEO Energy)
  - Peter Campbell – Project Director
  - Guy Cook – Project Manager
  - Andrew Walker – Project Engineer
  - Stephanie Walker – HSEQ
  - Dr Joe Ferris
- BMT Cordah
  - Dr Dorota Bastrikin – Environmental Support
  - Gareth Jones – CA Facilitator

Name	Signature	Role
Peter Campbell		Project Director
Guy Cook		Project Manager
Andrew Walker		Project Engineer
Stephanie Walker		HSEQ
Dr Joe Ferris		Environmental Advisor
Dr Dorota Bastrikin		Environmental Advisor
Gareth Jones		CA workshop Facilitator
Holly Mitchell	NOT PRESENT	BEIS Representative

Figure 3.1: Signed list of CA workshop attendees

3.2 CA Approach

The individual decommissioning options were assessed against five main criteria:

- Technical Feasibility;
- Safety;
- Environmental;
- Societal;
- Economic.

Firstly, an assessment of the Technical Feasibility of the decommissioning approaches considered was undertaken, using the following sub-criteria:

- Technical Risk; and
- Ease of Recovery from Excursion

Technical Feasibility criterion was assessed using the descriptors provided in Appendix B. All options, which scored between minor and moderate for technical feasibility, were taken forward for further assessment against the remaining criteria. The remaining criteria were assessed against a mix of qualitative and quantitative approaches (Table 3.1). The individual methodologies are described in Appendices B-F.

Table 3.1: Assessment criteria and methodology used

Criteria/ Sub criteria		Assessment methodology	Appendix reference
Technical Feasibility	Technical risk	Qualitative	Appendix B
	Ease of recovery from execution		
Safety	Risk to other users of the sea (post ops)	Qualitative	Appendix C
	Risk to other users (during ops)		
	Risk to personnel		
	Level of diver intervention	Quantitative	
Environmental	Environmental risk	Qualitative	Appendix D
	Energy use	Quantitative	Appendix E
	Atmospheric emissions		
Societal	Commercial fishers	Qualitative	Appendix D
	Other offshore users		
	Onshore communities		
	Legacy issues		
Economic	Economic risk	Quantitative	Appendix F

3.3 Scoring Assessment

To enable a comparison to be made of the decommissioning options, the results were collated and compared using a normalised/ weighted scoring system. The results of each of the assessments were expressed in common units and ranked in order of performance from best to worst, based on the weightings assigned (**Table 3.2**). Decommissioning Guidance Notes (DECC, 2011), upon which this method was principally based, make provision for weightings to be assigned to the scoring for the individual assessments to transparently reflect the proportionality/ or balancing of the options from the viewpoint of the operator or its stakeholders.

Once the overall values were established, sensitivity analysis was performed to test the robustness of the assessment. This was carried out by removing the criteria from consideration (one-by-one) by applying the maximum score across all options. The analysis was carried out to identify any criteria that may be driving the selection of a particular option and to remove any uncertainty from the comparative assessment. The results of this analysis are presented in Section 5.3.

Table 3.2: Weightings for criteria assigned by NEO

Criteria/ sub-criteria	Weighting (percentage) per sub-criterion	Weighting (percentage) per criterion
Technical Feasibility – Technical Risk	10	20
Technical Feasibility – Ease of Recovery from Excursion	10	
Safety – Risk to other users of the sea (post ops)	7.5	30
Safety – Risk to other users (during ops)	7.5	
Safety – Risk to personnel	7.5	
Safety – Level of diver intervention	7.5	
Environmental – Environmental risk	10	20
Environmental – Energy use	5	
Environmental – Atmospheric emissions	5	
Societal – Commercial fishers	2.5	10
Societal – Other offshore users	2.5	
Societal – Onshore communities	2.5	
Societal – Legacy issues	2.5	
Economic – Economic risk	20	20
Total	**100**	**100**

3.3.1 Option Selection

The maximum weighting was assigned to the best scoring decommissioning option for each individual criterion.

$$Weighted\ score = \frac{best\ performing\ option\ score}{current\ option\ score} \times weighting$$

All subsequent decommissioning options were assigned a normalised weighted value in proportion to the best performing option. The output was a matrix presenting normalised/ weighted values for the criteria/ sub-criteria for every decommissioning option being considered. An overall value was established by totalling the normalised/ weighted values for the assessments and comparing the options.

4.0 COMPARATIVE ASSESSMENT RESULTS

The following section presents the results of the CA of the five pipeline decommissioning options and six flushing options. Sections 4.1 to 4.5 highlight why the decommissioning options were considered to be strongly or weakly differentiated from each other and provides a more detailed explanation for the scores awarded to each decommissioning method.

4.1 Technical Feasibility Differentiation

The results of the technical feasibility assessment for pipeline decommissioning and flushing options, undertaken at the CA workshop are presented in Appendix B and summarised in **Tables 4.1** and **4.2**, respectively.

NEO's Technical Feasibility assessment has been based on the following Technical sub-criteria:

- Technical Risk; and
- Ease of Recovery from Excursion

Details of the methodology are provided in Appendix B.

A maximum normalised/ weighted score of 10.0 (**Table 3.2**) was applied to the most preferable (lowest risk) option for each of the two sub criteria, totalling 20.0 for overall Technical Feasibility score.

Table 4.1: Technical Feasibility assessment results and normalised weightings for pipeline decommissioning options

Option	Technical risk		Ease of recovery from excursion		Combined normalised scores
	Risk score	Normalised weighted score	Risk score	Normalised weighted value	
P1. Full removal – subsea cut and lift	2	5.0	2	10.0	15.0
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	1	10.0	2	10.0	20.0
P2b. Partial removal – ends, midline exposures and umbilical removed	1	10.0	3	6.7	16.7
P3a. Leave in situ – ends and midline exposures, removed with remediation where required	1	10.0	3	6.7	16.7
P3b. Leave in situ – ends, midline exposures and crossing removed	1	10.0	2	10.0	20.0

The partial removal Option P2a and leave in situ Option 3b are the best performing options, both with a normalised weighted score of 20.0. These methods scored risk values of 1 for technical risk and 2 for ease of recovery from excursion. The low scorings are due to the fact that well known technique will be used, which is a common practice and due to the current and historic burial status.

Option P1, full removal, scored 15 due to minor technical challenges having to be addressed in order to undertake the proposed work. Options P2b and P3a scored 16.7, due to additional interfaces required with Harbour Energy regarding the crossing remaining in situ.

Table 4.2: Technical Feasibility assessment results and normalised weightings for flushing options

Option	Technical risk		Ease of recovery from excursion		Combined normalised scores
	Risk score	Normalised weighted score	Risk score	Normalised weighted value	
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	2	5.0	3	3.3	8.3
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	1	10.0	2	5.0	15.0
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	1	10.0	2	5.0	15.0
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	1	10.0	2	5.0	15.0
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	1	10.0	1	10.0	20.0
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	1	10.0	1	10.0	20.0

The best performing options were F5 and F6, with normalised/ weighted score of 20.0 each. Those options are the easiest from the technical point of view, while remaining options are more complex, especially in relation to ease of recovery from an excursion, where the other options may require weeks (Option F1) or days (Options F2 to F4) to mobilise/ recover if an issue arises with flushing and/ or processing fluids.

4.2 Safety Differentiation

This section presents a comparison of the qualitative safety risk scores for each of the pipeline decommissioning and flushing options carried out as a desktop exercise. These scores were determined through a qualitative approach assessing likelihood of an incident occurring and the perceived severity of that incident on the receiving individual(s).

Table 4.3 provides a summary of the scores for each option and each normalised/ weighted value, which assigns a maximum score of 30 to the best performing option for pipeline decommissioning, and then scores the remaining options in inverse proportion to their overall risk scores. **Table 4.4** provides summary of this same approach for the flushing options. Appendix C provides a breakdown of the individual scores associated with each pipeline decommissioning and flushing option, along with the scoring matrix and descriptors for the ‘likelihood’ and ‘consequence’ scoring criteria.

Table 4.3: Qualitative safety assessment results and normalised weightings of pipeline decommissioning options

Option	Summed total	Normalised/ weighted score
P1. Full removal – subsea cut and lift	30	20.0
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	30	20.0
P2b. Partial removal – ends, midline exposures and umbilical removed	22	27.3
P3a. Leave in situ – ends, midline exposures and midline sections removed	20	30.0
P3b. Leave in situ – ends, midline exposures and crossing removed	22	27.3

The leave in situ option (Option P3a) can be differentiated from the other options by having markedly lower requirements for subsea intervention (disconnection of pipelines and reburial of open ends), lower risk to decommissioning workforce offshore (fewer lifts and less dive intensive) and associated transport on land for the removed material (reducing risk to the decommissioning workforce).

There was a perceived increase in risk in particular to commercial fishermen compared to the full removal methods due to the infrastructure remaining on the seabed. However, as the pipeline is assumed to be buried, which will be determined by planned 2019 pipeline burial survey, this can be adequately mitigated against with communication, monitoring and accurate reporting of the final location of infrastructure post-decommissioning. If this option is selected, also a post-decommissioning clearance survey would be conducted to ensure no further remediation is required. Differing methods of verification of the seabed state will be undertaken i.e. trawl at sites where actual decommissioning works occur, and, due to the sensitive environmental setting, an alternative will be undertaken along the pipeline corridors, where decommissioning work has not taken place. Post decommissioning methods will be discussed and agreed with OPRED in due course.

The full removal option (Option P1) was the worst performing. The main differentiator was the amount of time to undertake the removal operations increasing the exposure to risk along with the increased risk to 3rd parties, both offshore through increased vessel operations, and onshore with the transport of the large volume of material by lorry on the road network, increasing the risk of exposure through road traffic accidents.

Table 4.4: Qualitative safety assessment results and normalised weightings of flushing options

Option	Summed total	Normalised/ weighted score
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	16	30.0
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	21	22.9
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	21	22.9
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	21	22.9
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	18	26.7
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	18	26.7

The Option F1 can be differentiated from the other options by having lower associated transport, and downhole disposal of flushing fluids (reducing risk to 3rd parties and decommissioning workforce). However, no major differences between the options were identified.

4.3 Environmental Differentiation

The environmental criterion is split into three sub-criteria. Environmental risk is described in Section 4.3.1 and the energy and emissions sub-criteria results are described in Section 4.3.2. The combined scores and weightings are presented in Section 4.3.3.

4.3.1 Environmental Risk

This criterion was assessed during a CA workshop using a qualitative traffic light assessment, which is described in Appendix D.

The assessment enabled a distinction to be made between three categories of risk: Red (high), Amber (medium) and Green (low). Differentiation between pipeline decommissioning and flushing options was based on the level of risk assessed for each receptor and the total number of potentially impacted receptors per option. Values were assigned to the risk categories to allow numerical calculations, these were based on the median values for the risk bandings from NEO's risk matrix, which is described in Appendix C, **Table C.4** (Red 18, Amber 8.5, Green 2.5).

The assessments included the completion of risk assessment worksheets (Appendix D), which addressed the pipeline decommissioning and flushing options. Totals (**Tables 4.5** and **4.6**) were calculated from the worksheets by adding the risk values assigned to each receptor and summing the values associated with each option. The summed totals were normalised by the weights assigned by NEO with the maximum weighted value assigned to the decommissioning option with the lowest risk. The subsequent normalised/ weighted values were then calculated in relation to the option with the lowest risk.

Table 4.5: Environmental risk assessment results and normalised weightings of pipeline decommissioning options

Option	Summed total	Normalised/ weighted score
P1. Full removal – subsea cut and lift	71.5	4.5
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	50	6.4
P2b. Partial removal – ends, midline exposures and umbilical removed	50	6.4
P3a. Leave in situ – ends, midline exposures and midline sections removed	32	10.0
P3b. Leave in situ – ends, midline exposures and crossing removed	38	8.4

For the pipeline decommissioning the key environmental receptors that differentiate the options are seabed disturbance, air quality, benthos, fish and shellfish, and marine mammals.

Option P3a scored most favourably (32)[1] and was considered to have the smallest environmental impact, therefore has the highest normalised/ weighted value of 10.0. Option P3a (leave in situ – open ends of pipeline reburied) differs from Options P1, P2a and P2b by the fact that the pipeline and umbilical would not be removed and/ or there would be minimal disturbance to the current seabed state. Option P3a proposes to remove only pipeline ends thus reducing the long-term impact by freeing those sections of seabed and removing future risk to the other users of the sea (snagging).

Option 3b scored 8.4; due to extra vessel activity for removal of the crossing there is increased potential for an impact to marine mammals, in comparison with Option 3a.

Options P1 scored 4.5; the main impact is derived from the seabed disturbance caused by exposing the pipeline for removal. Non-intrusive post-decommissioning inspections (as agreed with OPRED in due course) would be carried out to ensure that any pipeline trench remaining is safe for other sea users.

Options P2a and P2b (partial removal) are similar to Option P1, however, as this method proposes to remove only the umbilical, pipeline ends, spools (Option P2a and P2b) and crossing sections (Option P2a), this would result in the reduction of the seabed

[1] Following the workshop, it was deemed prudent to include a worst–case estimate for remediation to Option P3a. From the most recent (Petrex, 2021) pipeline survey report it is clearly shown that, with the exception of the AR pipeline crossing section, both the pipeline and the umbilical continue to remain trenched below the seabed throughout their lengths with typical burial depths of around 1.4m and limited evidence of exposure and no evidence of free spans. Unfortunately, recent predictions of future sand wave migration show that the pipeline and umbilical are each likely to become exposed at two distinct locations as a result of such bedform movement, thereby presenting a credible risk to fishing operations. On this basis and in addition to reburial (if required) of the cut ends at Victoria and Viking, it is now also the intent to cut and remove those mid-line sections of pipeline and umbilical that will become “at risk” of exposure. Following the CA workshop and analysis of the outcome of the CA, NEO consider that the outcome of the Environmental Risk associated with Option P3a would not differ from the original scoring.

disturbance. It is anticipated that there will be less cuts under these options, when compared to decommissioning Option P1. Each of these options was given a normalised weighted value of 6.4.

Due to sensitive environmental setting in the Victoria area non-intrusive methods of verification of the seabed state will be undertaken following decommissioning activities. The appropriate methods will be discussed and agreed with OPRED, as required. The effect of any short-term disturbance from removal of mattresses and the valve skid to the seabed has not been assessed in the comparative assessment as this will be common across all options. However, it should also be noted that due to the dynamic nature of the currents at the seabed the physical disturbance would be short-term, temporary and not significantly above natural variability.

For the flushing operations, key environmental receptors that differentiate the options are water and air quality, fish and shellfish, marine mammals and conservation sites, which are determined by the number of vessels involved and the destination of the flushing fluids.

Options F1 to F4 scored most favourably (23.5) and were considered to have the smallest environmental impact, therefore have the highest normalised/ weighted value of 10.0. Options F1 to F4 differ from remaining two options by the fact that the flushing fluids will be disposed downhole (Option F1) or collected for disposal onshore (Options F2 to F4).

Options F5 and F6 scored 5.7; the main impacts are derived from the disposal of flushing fluids to sea (Option F5) or leaving the contents of the pipeline to free flood (Option F6), which has a potential to contaminate the water column and seabed affecting water quality, fish and shellfish, marine mammals and conservation sites.

Table 4.6: Environmental assessment results and normalised weightings of flushing options

Option	Summed total	Normalised/ weighted score
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	23.5	10.0
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	23.5	10.0
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	23.5	10.0
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	23.5	10.0
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	41.5	5.7
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	41.5	5.7

4.3.2 Energy Use and Atmospheric Emissions

This section presents the quantitative estimates of energy usage and subsequent atmospheric (CO_2) emissions that provide the basis for differentiating between each pipeline decommissioning and flushing option. The method outlined in Appendix E follows the "Guidelines for Calculation of Energy Use and Gaseous Emissions in Decommissioning" (IoP, 2000).

The method considers the fate of decommissioned material from pre-decommissioning preparation to an onshore end-point, such as recycling or disposal to landfill. Appendix E provides further detail on the energy and emissions methodology assumptions and results.

Tables 4.7 and **4.8** provide a summary of the energy use (in giga joules (GJ)) and emissions (in tonnes of CO_2) for each pipeline decommissioning and flushing option, respectively. The maximum normalised/ weighted value has been assigned to the most preferable (lowest risk option). Energy and emissions have been assigned a maximum weighting of 10, which has subsequently been divided between energy use and emissions (a maximum weighted value of 5 for each). The scores for the remaining options have been calculated in inverse proportion to their overall summed totals.

Table 4.7: Energy and emissions assessment results and normalised weightings for pipeline decommissioning options

Option	Energy		Emissions		Combined normalised/ weighted score
	Energy Usage (GJ)	Normalised weighted score	Emissions (Tonnes CO_2)	Normalised weighted score	
P1. Full removal – subsea cut and lift	59,485	3.9	4,505	3.9	7.7
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	54,355	4.2	4,080	4.3	8.5
P2b. Partial removal – ends, midline exposures and umbilical removed	52,391	4.4	3,934	4.4	8.8
P3a. Leave in situ – ends and midline exposures removed	46,187	5.0	3,473	5.0	10.0
P3b. Leave in situ – ends, midline exposures and crossing removed	48,250	4.8	3,627	4.8	9.6

Decommissioning Option P3a (leave in situ) is ranked as resulting in the lowest impact for energy use and emissions (weighted score of 10). The Option 3b performed slightly worse for energy use and emissions with overall score of 9.6. Use of additional vessels for additional activities offshore was a deciding factor. The Options P2a and P2b (partial removal) scores were 8.5 and 8.8, respectively. This is a direct result of lower vessel time and onshore transport requirements in comparison with the lowest performing Option P1 (full removal), which scored 7.7.

Despite the differences in energy use and CO_2 emissions between options, the recycling and remanufacturing elements of the calculation counterbalance some of the increase associated with the vessel usage. For example, the removal options have less material to remanufacture, as most of the material can be recycled, however, they have the greatest vessel usage. In contrast, the leave in situ option requires the vast majority of the material to be remanufactured due to recyclable materials being left in situ but have minimal vessel usage associated with the decommissioning activities.

A full breakdown of the contributing factors and their relating energy and emission values are presented in Appendix E.

Table 4.8: Energy and emissions assessment results and normalised weightings for flushing options

Option	Energy		Emissions		Combined normalised/ weighted score
	Energy Usage (GJ)	Normalised weighted score	Emissions (Tonne/ CO_2)	Normalised weighted score	
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	7,689	3.4	571	3.4	6.8
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	23,455	1.2	1,741	1.2	2.4
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	22,438	1.2	1,666	1.2	2.4
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	10,543	2.5	783	2.5	5.0
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	6,155	4.3	457	4.3	8.6
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	5,237	5.0	389	5.0	10.0

Decommissioning Option F6 (free flood, no flushing) is ranked as resulting in the lowest impact from the energy use and emissions (weighted score of 10.0), due to the lowest number of vessels required.

The poorest performing Options F2 and F3 (both scored 2.4) require use of vessels and a rig, which is associated with much higher emissions. The differentiation between the options was based on the difference in the number and type of vessels involved in the operations as the major factor. A full breakdown of the energy and emission values is presented in Appendix E.

4.3.3 Combined normalised environmental risk results

Tables 4.9 and **4.10** provide a summary of the combined environmental sub-criteria scoring for pipeline decommissioning and flushing options, respectively.

Table 4.9: Combined normalised weighted scores of environmental risk for pipeline decommissioning options

Option	Normalised weighted scores			Combined normalised/ weighted score
	Environmental risk	Energy Usage (GJ)	Emissions (Tonnes CO_2)	
P1. Full removal – subsea cut and lift	4.5	3.9	3.9	12.2
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	6.4	4.2	4.3	14.9
P2b. Partial removal – ends, midline exposures and umbilical removed	6.4	4.4	4.4	15.2
P3a. Leave in situ – ends and midline exposures removed	10	5.0	5.0	20.0
P3b. Leave in situ – ends, midline exposures and crossing removed	8.4	4.8	4.8	18.0

Table 4.10: Combined normalised weighted scores of environmental risk for pipeline flushing options

Option	Normalised weighted scores			Combined normalised/ weighted score
	Environmental risk	Energy Usage (GJ)	Emissions (Tonnes CO_2)	
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	10.0	3.4	3.4	16.8
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	10.0	1.2	1.2	12.4
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	10.0	1.2	1.2	12.4
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas	10.0	2.5	2.5	15.0

vented on the PSV, fluids collected for disposal onshore.				
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	5.7	4.3	4.3	14.3
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	5.7	5.0	5.0	15.7

4.4 Societal Differentiation

This criterion was assessed during the CA Workshop using a qualitative traffic light assessment, which is described in Appendix D. This section summaries the results.

The assessment enabled a distinction to be made between three categories of risk: Red (high), Amber (medium) and Green (low). Differentiation between pipeline decommissioning and flushing options was based on the level of risk assessed for each receptor and the total number of potentially impacted receptors per option. Values were assigned to the risk categories to allow numerical calculations, these were based on the median values for the risk bandings from NEO's risk matrix which is described in Appendix C, **Table C.4** (Red 18, Amber 8.5, Green 2.5).

The assessments included the completion of risk assessment worksheets (Appendix D), which addressed the pipeline decommissioning and flushing options. Totals (**Tables 4.11** and **4.12**) were calculated from the worksheets by adding the risk values assigned to each receptor and summing the values associated with each option. The summed totals were normalised by the weights assigned by NEO with the maximum weighted value assigned to the decommissioning option with the lowest risk. The subsequent normalised/ weighted values were then calculated in relation to this lowest risk option.

Table 4.11: Societal risk assessment results and normalised weightings of pipeline decommissioning options

Option	Summed total	Normalised/ weighted score
P1. Full removal – subsea cut and lift	16	10.0
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	22	7.3
P2b. Partial removal – ends, midline exposures and umbilical removed	22	7.3
P3a. Leave in situ – ends, midline exposures and midline sections removed	16	10.0
P3b. Leave in situ – ends, midline exposures and crossing removed	16	10.0

For the pipeline decommissioning key societal receptors that differentiate the options are onshore communities and legacy issues, which are determined by the level of associated intervention.

Options P1, P3a and P3b scored most favourably (16.0)[2] and were considered to have the smallest societal impact and therefore have the highest normalised/ weighted value of 10.0 each. Option P1 (full removal) will pose no snagging risk or legacy issues, however will impact onshore communities due to use of landfill sites and recycling facilities, Option P3a (Leave in situ – open ends of pipeline reburied) will result in a minimal risk of snagging and loss of fishing gear to other users of the sea as the pipeline deteriorates over time, while Option 3b (Leave in situ – open ends of pipeline buried, crossing removed) will have a risk of snagging further minimised due to removal of crossing. Options P2a and P2b (partial removal) have slightly higher risk of snagging due to the infrastructure that will be left behind and ongoing legacy issues, as well as impacting onshore communities by use of landfill sites and onshore recycling. Each of these options was given a normalised weighted value of 7.3.

Table 4.12: Societal assessment results and normalised weightings of flushing options

Option	Summed total	Normalised/ weighted score
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	10	10.0
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	16	6.3
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	16	6.3
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	16	6.3
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	10	10.0
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	10	10.0

[2] Following the workshop, it was deemed prudent to include a worst–case estimate for remediation to Option P3a. From the most recent (Petrex, 2021) pipeline survey report it is clearly shown that, with the exception of the AR pipeline crossing section, both the pipeline and the umbilical continue to remain trenched below the seabed throughout their lengths with typical burial depths of around 1.4m and limited evidence of exposure and no evidence of free spans. Unfortunately, recent predictions of future sand wave migration show that the pipeline and umbilical are each likely to become exposed at two distinct locations as a result of such bedform movement, thereby presenting a credible risk to fishing operations. On this basis and in addition to reburial (if required) of the cut ends at Victoria and Viking, it is now also the intent to cut and remove those mid-line sections of pipeline and umbilical that will become "at risk" of exposure. Following the CA workshop and analysis of the outcome of the CA, NEO consider that the outcome of the Environmental Risk associated with Option P3a would not differ from the original scoring.

For the flushing operations, the key societal receptor that differentiates the options is impact to onshore communities, which is determined by treatment of flushing fluids onshore.

Options F1, F5 and F6 scored most favourably and were considered to have the smallest societal impact and therefore have each the highest normalised/ weighted value of 10.0. Options F1, F5 and F6 differ from remaining three options by the fact that the flushing fluids will be disposed offshore (Option F1 – downhole, Option F5 – flushed to sea, Option F6 – free flooding, no flushing).

Options F2, F3 and F4 scored 6.3; the main impacts are derived from the treatment and disposal of flushing fluids onshore, which will impact use of the onshore resources.

4.5 Economic Differentiation

This section provides cost estimates for the pipeline decommissioning and flushing options. Vessel costs have been estimated by vessel days and rates provided by NEO. **Table 4.13** provides a comparison for the five pipeline decommissioning options and **Table 4.14** for six flushing options, ranked by cost (economic). Appendix G provides a full description of estimated costs for each pipeline decommissioning and flushing option. The maximum normalised/ weighted value was assigned to the most preferable (lowest cost method). The values for the remaining methods have been calculated in inverse proportion to their overall summed totals.

It should be noted that all costs are based on absolute worst-case estimates (i.e. including contingency vessel days) for the sake of Comparative Assessment and will not necessarily reflect actual costs.

Option P3a is the least expensive option at a cost of £10.3 million and has the highest weighted score of 20.0. This is a result of the option having the minimum number of vessels and minimal number of days to complete the decommissioning and remediation works.

Table 4.13: Cost estimates and normalised weightings for pipeline decommissioning options

Option	Estimated cost (million £)	Normalised/ weighted score
P1. Full removal – subsea cut and lift	16.1	12.8
P2a. Partial removal – ends, midline exposures, crossing and umbilical removed	12.8	16.1
P2b. Partial removal – ends, midline exposures and umbilical removed	12.2	16.9
P3a. Leave in situ – ends, midline exposures and midline sections removed	10.3	20.0
P3b. Leave in situ – ends, midline exposures and crossing removed	10.8	19.1

Options P2a and P2b have costs of £12.8 and £12.2 million, and weighted scores of 16.1 and 16.9, respectively. These options have similar numbers of operational and disposal/

recycling costs, with the only differences attributed to the different number of vessels required to remove the crossing.

Option P3b has costs of £10.8 million, also as a result of additional resources required for the pipeline crossing removal.

Option P1 is the most expensive option with estimated costs of £16.1 million and has the lowest weighted score of 12.8. The costs for Option P1 can primarily be attributed to the number of DSV operational days (81 days) and the vessel daily cost (approximately £180,000 per day). This option also has higher disposal/ recycling costs than the other three options.

Costs for post decommissioning inspections have been added to all pipeline options with partial removal/ decommission in situ options. In due course, OPRED will determine and agree with NEO an appropriate risk-based monitoring programme for pipelines left in situ.

Option F6 is the least expensive option at a cost of £0.68 million and has the highest weighted score of 20.0. This is a result of the option having the minimum number of vessels and minimal number of days to complete the operations, as no flushing is involved. This option is closely followed by Option F5 at a cost of £0.79 million and a weighted score of 17.1, which involves slightly longer vessel time for flushing pipeline contents to sea.

Option F2 is the most expensive options with estimated costs of £1.60 million and has the lowest weighted scores of 8.5. The costs for Option F2 can primarily be attributed to the number of DSV and rig operational days and equipment cost.

The remaining three options scored 9.1 (Option F4), 9.7 (Option F3) and 12.0 (Option F1), with costs between £1.50 and £1.13 million, differentiated by the type of vessels required and number of operational days.

Table 4.14: Cost estimates and normalised weightings for flushing options

Option	Estimated cost (million £)	Normalised/ weighted score
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	1.13	12.0
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	1.60	8.5
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	1.40	9.7
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	1.50	9.1
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	0.79	17.1
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	0.68	20.0

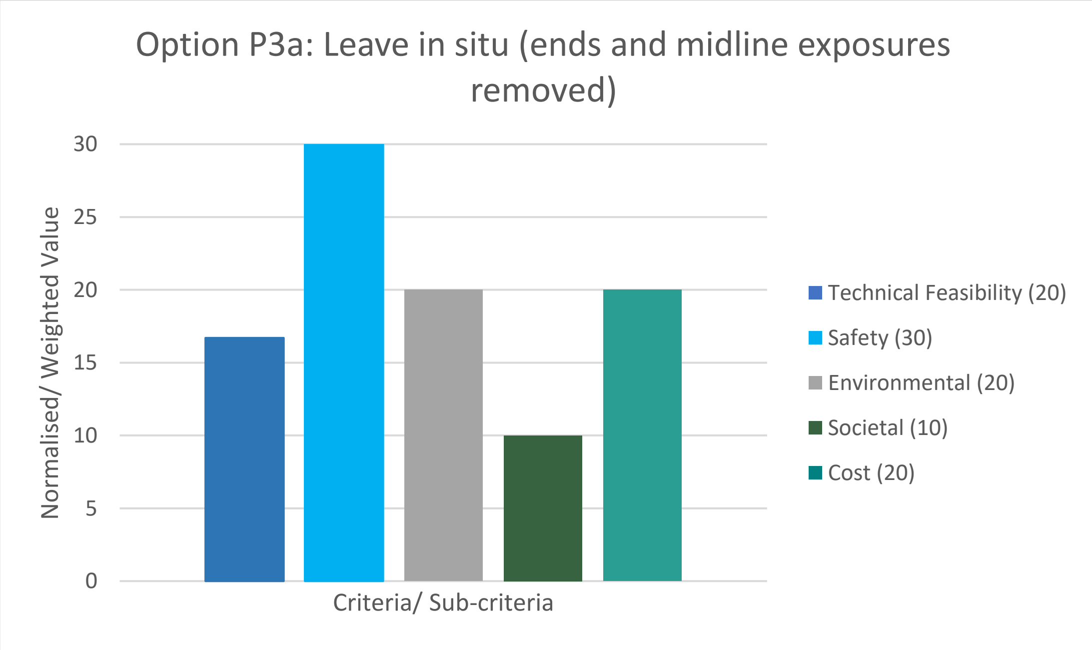
5.0 CONCLUSIONS

The cumulative scoring of the criteria for the pipeline decommissioning options are listed below from the highest to the lowest scores in Section 5.1. The pipeline flushing options are presented in Section 5.2. The performances of the evaluation criteria for the options are represented graphically such that the higher normalised weighted value the better the outcome.

5.1 Pipelines Decommissioning Options

Option P3a: Leave in situ (ends and midline sections removed).

Leave in situ scored highest (**96.7/ 100**) due to a good performance against the majority of the criteria (**Figure 5.1**).

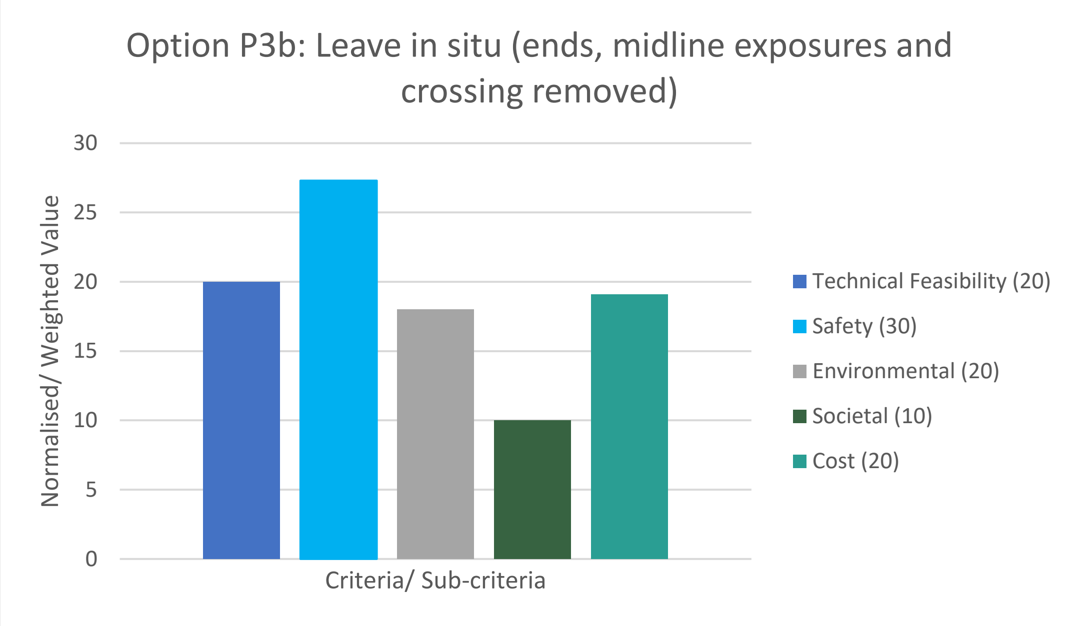


[Total scores available for each criteria given in brackets]

Figure 5.1: Weightings per criteria for Option P3a Leave in situ (ends and midline exposures removed)

Option P3b: Leave in situ (ends, midline exposures and crossing removed).

Leave in situ (ends, midline exposures and crossing removed, remainder of pipeline and umbilical stay in situ) ranked second (**94.4/ 100**). This option scored similarly to Option P3a, with stronger performance against the Technical Feasibility, but slightly poorer against Safety, Environmental and Economic criteria (**Figure 5.2**).

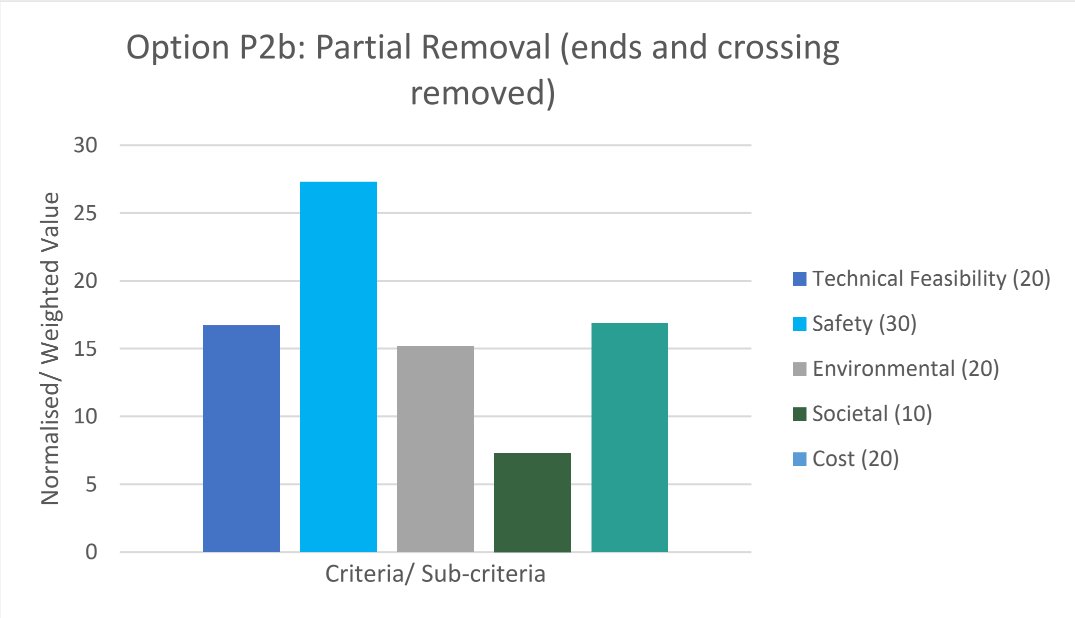


[Total scores available for each criteria given in brackets]

Figure 5.2: Weightings per criteria for Option P3b: Leave in situ (ends, midline exposures and crossing removed)

Option P2b: Partial removal (ends, midline exposures and umbilical removed).

Partial removal (ends removed, midline exposures removed, whole umbilical removed) ranked third (**83.4/ 100**). This option had strong performance against the Safety, Cost and Environmental criteria (**Figure 5.3**).

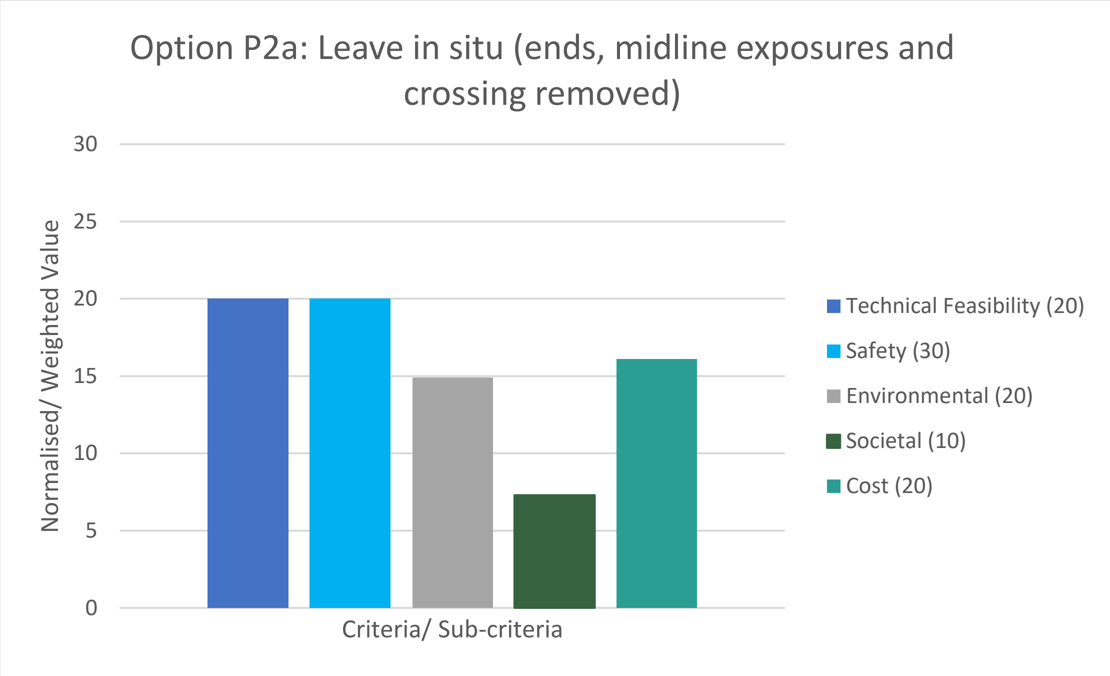


[Total scores available for each criteria given in brackets]

Figure 5.3: Weightings per criteria for Option P2b: Partial removal (ends, midline exposures and umbilical removed)

Option P2a: Partial removal (ends, midline exposures, crossing and umbilical removed).

Partial removal (ends, midline exposures and crossing removed, whole umbilical removed) ranked fourth (**78.3/ 100**). This option scored similarly to Option P2b but with a reduction in its performance against safety (**Figure 5.4**).

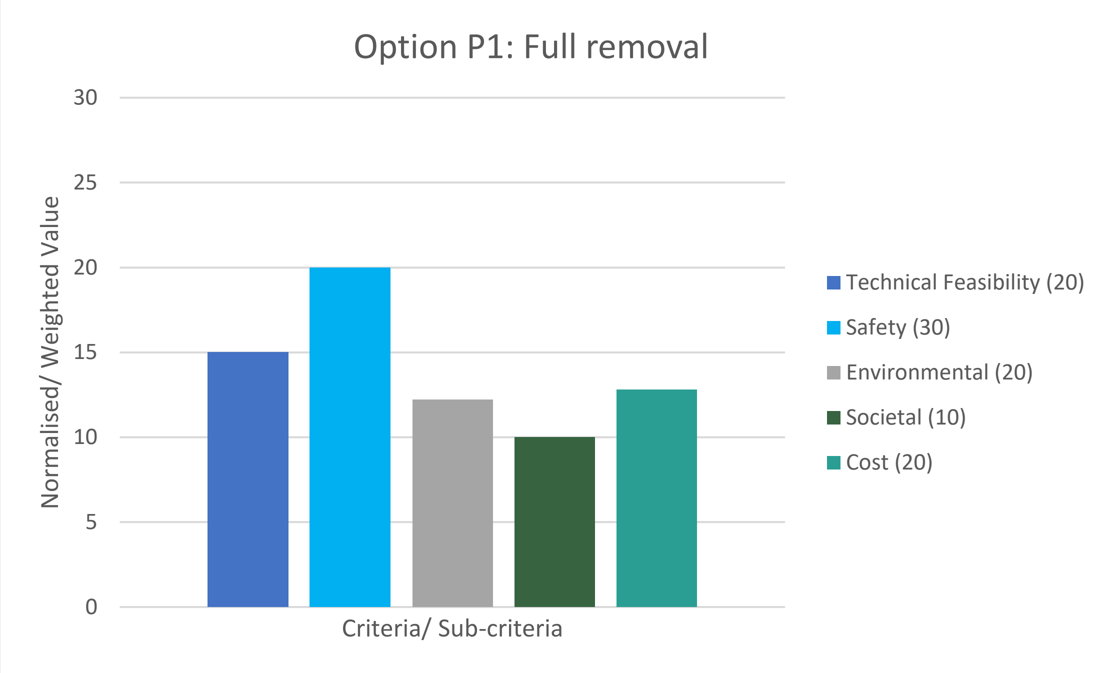


[Total scores available for each criteria given in brackets]

Figure 5.4: Weightings per criteria for Option P2a: Partial removal (ends, midline exposures, crossing and umbilical removed)

Option P1: Full removal

Full removal ranked forth (**70/ 100**). This option scored similarly to Option P2b but with a reduction in its performance against safety (**Figure 5.5**). This option performed worst against Safety, Economic, Environmental and Technical Feasibility compared to the other options.



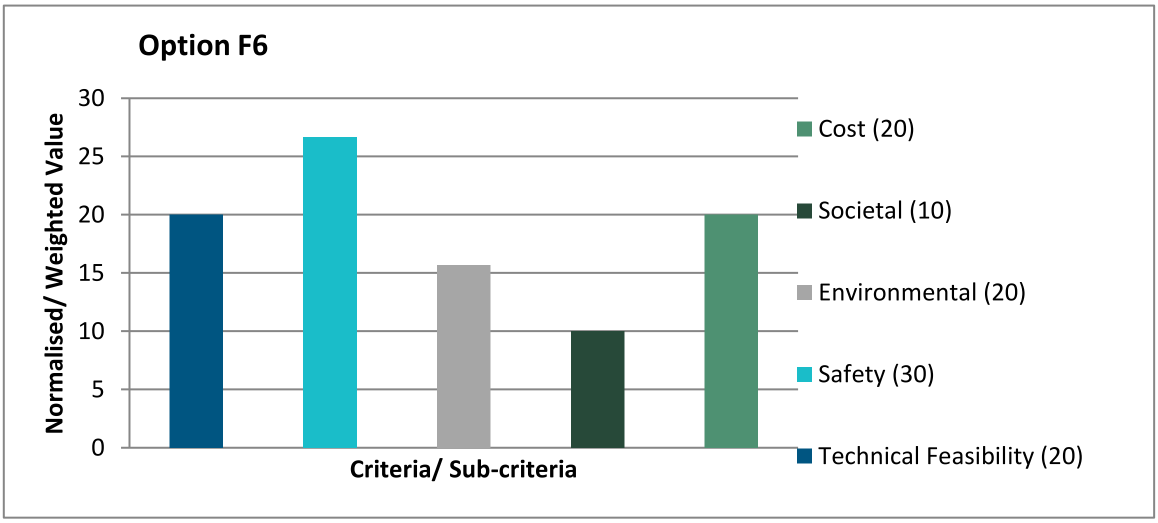
[Total scores available for each criteria given in brackets]

Figure 5.5: Weightings per criteria for Option P1: Full removal

5.2 Pipeline Flushing Options

Option F6: Use a vessel to open valves to allow free flooding of the pipeline, no flushing.

Option F6 ranked first (**92.4/ 100**). This was driven by strong performance against the Safety, Economic, Technical Feasibility, Societal and Environmental criteria (**Figure 5.6**).

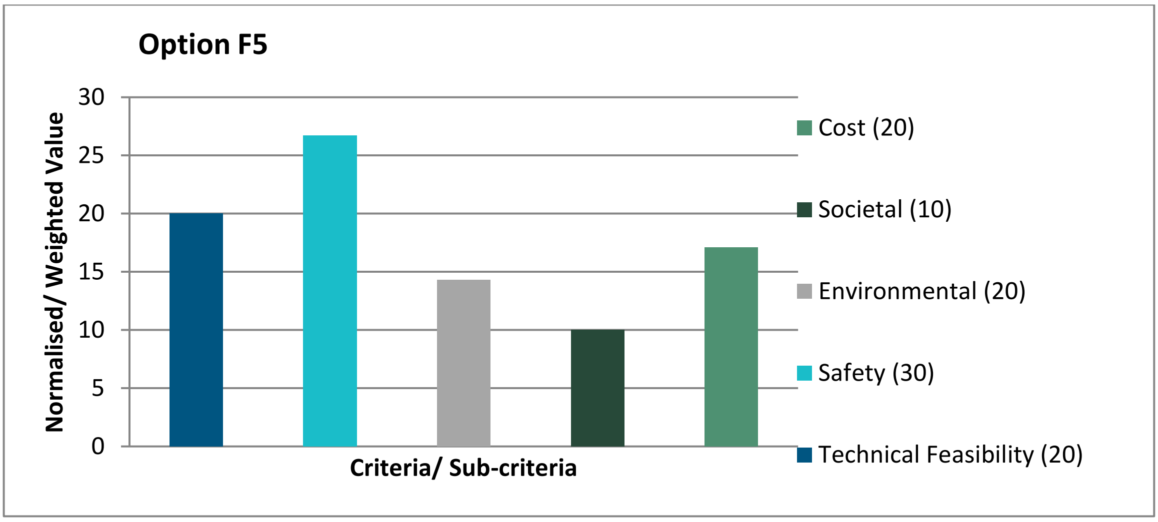


[Total scores available for each criteria given in brackets]

Figure 5.6: Weightings per criteria for Option F6 - use a vessel to open valves to allow free flooding of the pipeline, no flushing

Option F5: Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.

Option F5 ranked second (**88.1/ 100**) and is NEO's preferred option. This option differed from Option F6 in the Environmental and Economic criteria, however these differences were marginal (**Figure 5.7**). The option is preferred because of reduced potential risk to divers during removal activities.

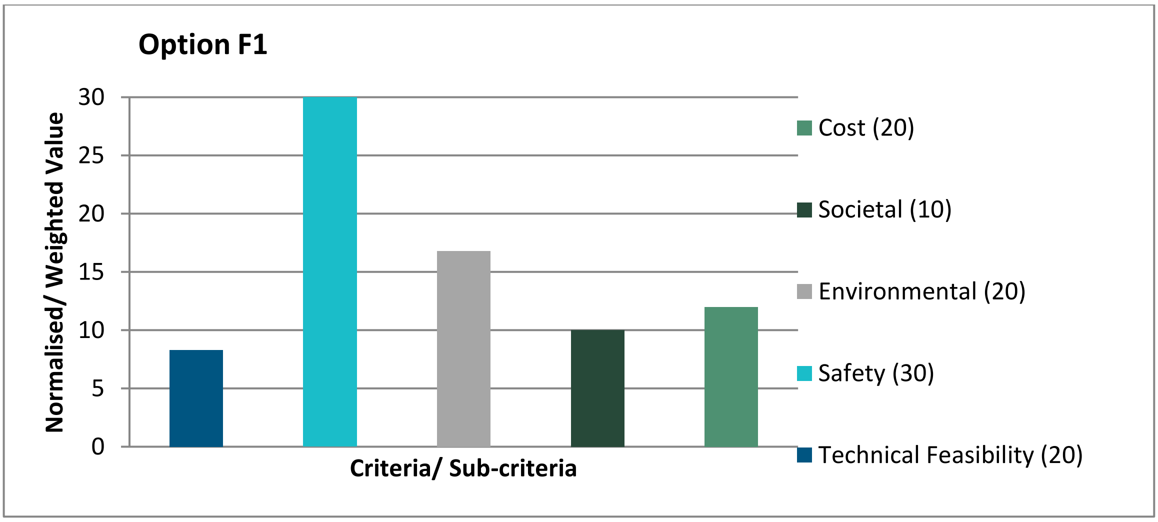


[Total scores available for each criteria given in brackets]

Figure 5.7: Weightings per criteria for Option F5 - use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.

Option F1: Flush from the Viking BD skid to the tree, re-inject fluids downhole.

Option F1 ranked third (**77.1/ 100**). This option performed poorly against Technical Feasibility but had best performance for Safety and Environmental criteria (**Figure 5.8**).

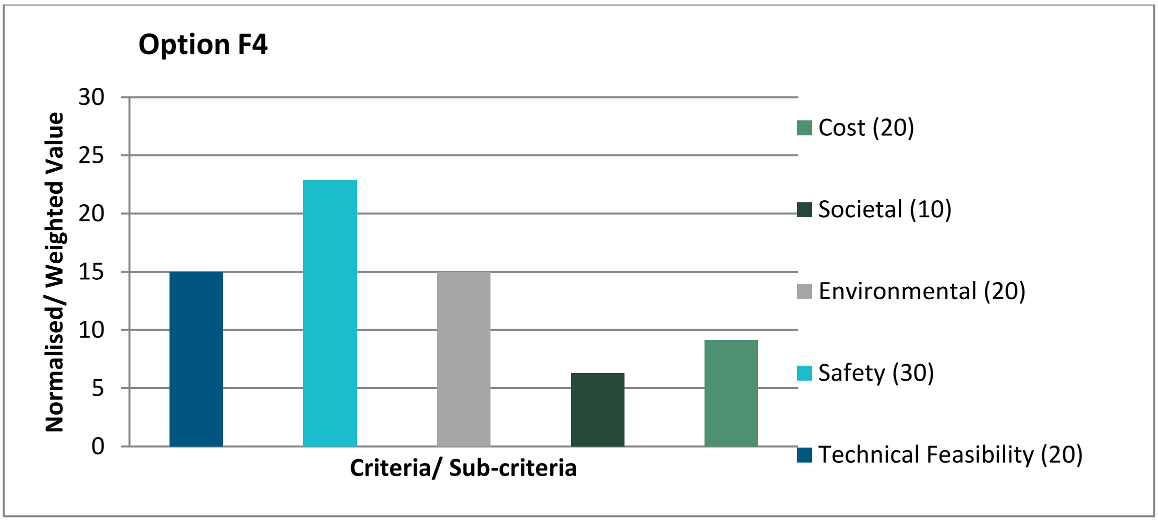


[Total scores available for each criteria given in brackets]

Figure 5.8: Option F1 - flush from the Viking BD skid to the tree, re-inject fluids downhole

Option F4: Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.

Option F4 ranked forth (**68.3/ 100**). This option performed similarly Options F2 and F3 with marginal differences associated with Environmental and Economic performance. This option performed joint worst against the Societal and Safety criteria along with Options F2 and F3 (**Figure 5.9**).

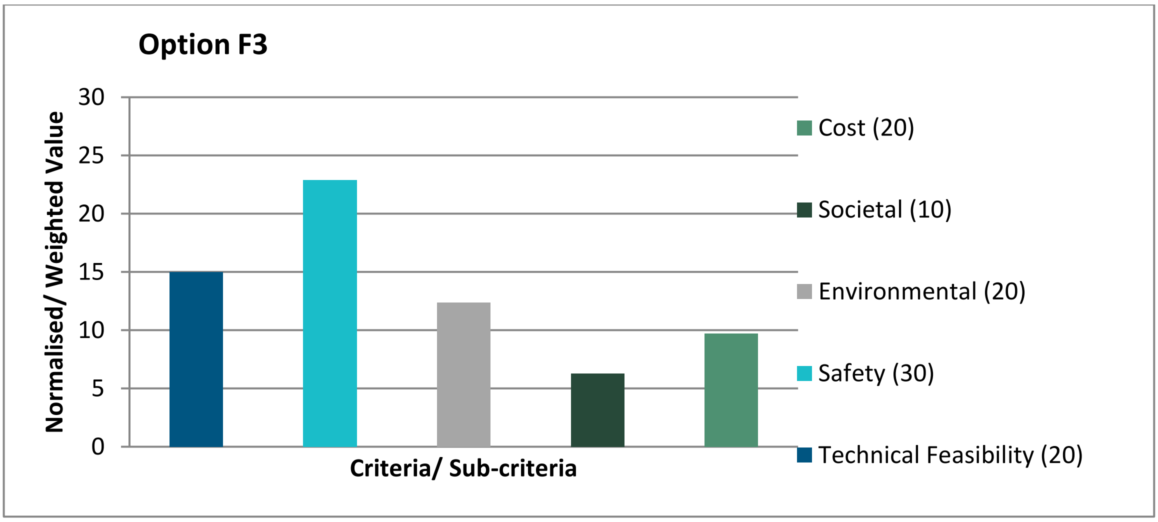


[Total scores available for each criteria given in brackets]

Figure 5.9: Option F4 - flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore

Option F3: Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.

Option F3 ranked fifth (**66.3/ 100**). This option performed similarly Options F2 and F4 with marginal differences associated with Environmental (against F4) and Economic (against F4 and F2) performance. This option performed joint worst against the Societal and Safety criteria along with Options F2 and F4. (**Figure 5.10**).

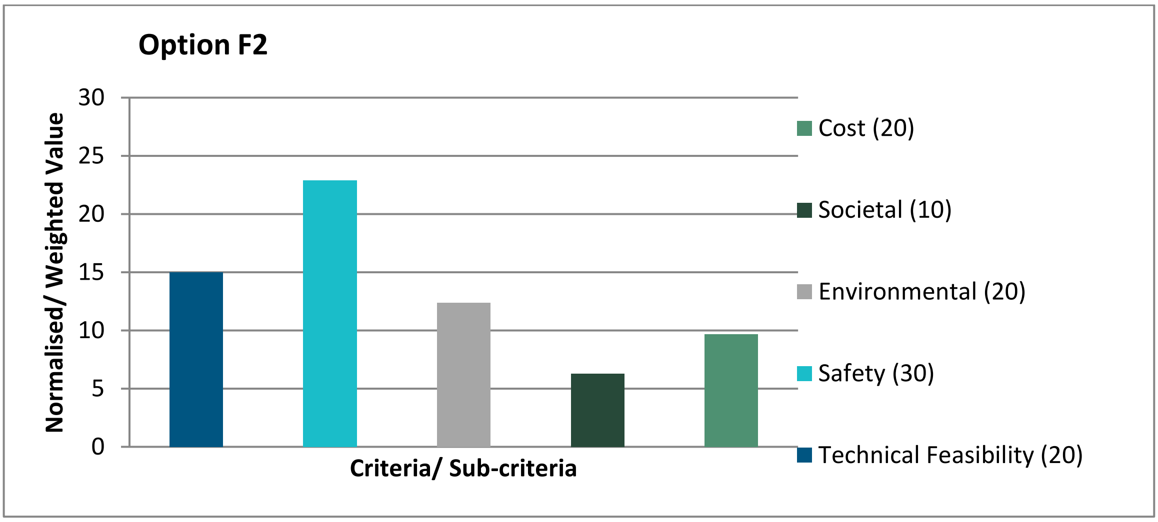


[Total scores available for each criteria given in brackets]

Figure 5.10: Option F3 - flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.

__**Option F2**: Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.__

Option F2 ranked sixth (**65.1/ 100**). This option performed similarly to Option F3 with a marginal decrease in the performance against the Economic criteria only. This option performed joint worst against the Societal and Safety criteria along with Options F3 and F4. (**Figure 5.11**).



[Total scores available for each criteria given in brackets]

Figure 5.11: Option F2 - flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.

5.3 Sensitivity Analysis

Tables 5.12 and **5.13** presents the results of the sensitivity analysis performed on the criteria for pipeline decommissioning options and flushing options, respectively. The colours shown in the chart were assigned during the assessment of each criterion to identify where each criterion scored under each option (i.e. red was assigned to the lowest scoring option and dark green to the highest).

The sensitivity analysis of the scoring for pipeline decommissioning options only differed with the results of the comparative assessment on one occasion (Safety results for Options P2a and P2b; **Table 5.12**).

Table 5.12: Summary table of the sensitivity analysis of the comparative assessment weighted scores/ results for pipeline decommissioning options

Option	CA Results (Control)	Sensitivity Analysis - Adjusted Scores				
		Technical Feasibility Excluded	Safety Excluded	Environmental Excluded	Societal Excluded	Economic Excluded
P1. Full removal (subsea cut and lift of pipeline; umbilical reeled onto a vessel)	**67.7**	72.7	77.7	75.1	65.9	77.1
P2a. Partial removal (ends and crossing removed, umbilical removed)	**78.7**	78.7	88.7	83.1	80.8	82.9
P2b. Partial removal (ends removed, umbilical removed)	**84.8**	88.1	87.5	88.8	87.2	87.3
P3a. Leave in situ (ends and midline sections removed)	**96.7**	100.0	96.7	96.7	96.7	96.7
P3b. Leave in situ (ends and crossing removed)	**92.7**	92.8	95.5	94.5	92.8	95.5

The sensitivity analysis of the scoring for flushing options (**Table 5.13**) differed with the results of the comparative assessment for Technical Feasibility (results for Options F1 and F5) and Environmental (results for Options F3 and F4). The scores come up identical for Options F2 and F3 when Economics is excluded (**Table 5.13**).

Table 5.13: Summary table of the sensitivity analysis of the comparative assessment weighted scores/ results for flushing options

Option	CA Report (Control)	Sensitivity Analysis - Adjusted Scores				
		Technical Feasibility Excluded	Safety Excluded	Environmental Excluded	Societal Excluded	Economic Excluded
F1. Flush from the Viking BD skid to the tree, re-inject fluids downhole.	**77.1**	88.8	77.1	80.3	77.1	85.1
F2. Flush from the Viking BD skid through the tree, onto the rig via the workover riser. Gas vented on the rig, fluids collected for disposal onshore.	**65.1**	70.1	72.2	72.7	68.8	76.6
F3. Flush from the Viking BD skid to the Victoria valve skid, onto the rig via a flowline spool from the rig. Gas vented on the rig, fluids collected for disposal onshore.	**66.3**	71.3	73.4	73.9	70.0	76.6
F4. Flush from the Viking BD skid to the Victoria valve skid and then into a collection vessel (PSV). Gas vented on the PSV, fluids collected for disposal onshore.	**68.3**	73.3	75.4	73.3	72.0	79.2
F5. Use a vessel to vent the pipeline to sea at Victoria valve manifold, and allow free flood from Victoria. Relocate vessel to Viking BD skid and flush remaining contents to sea.	**88.1**	88.1	91.4	93.8	88.1	91.0
F6. Use a vessel to open valves to allow free flooding of the pipeline, no flushing.	**92.4**	92.4	95.7	96.7	92.4	92.4

The differences, when excluding various criteria from the CA results, do not appear to influence the overall result and choice of most favourable option. The results of the sensitivity analysis therefore attest to the robustness of the approach of the CA.