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PDZ 400MW MOS

Concept Study Report Addendum

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Apollo for Celtic Sea Power

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Contents

1 Abbreviations

Al	Aluminium
CAPEX	Capital expenditure
CBA	Cost benefit analysis
CSP	Celtic Sea Power
Cu	Copper
DEVEX	Development expenditure
FEED	Front End Engineering Design
km	kilometre
kV	kilovolt
MOS	Multi-Offshore Substation
MW	Megawatt
OFTO	Offshore Transmission Owner
OPEX	Operational expenditure
PCC	Point of common coupling
PDZ	Pembrokeshire Demonstration Zone
RFQ	Request for Quotation
TNuoS	Transmission Network Use of System
WTG	Wind turbine generator

2 Introduction

This document is an addendum to the concept study report [1] produced by Apollo and Vekta Group for Celtic Sea Power (CSP). It is an extension to the cost benefit analysis (CBA) in Section 11 of 395-003-GRL-RPT-0003, however it considers a different set of 4 x 100MW hypothetical wind farms, comparing the costs of them connecting independently to onshore points of common coupling (PCC) vs connecting to the potential Pembrokeshire Demonstration Zone (PDZ) Multi-Offshore Substation (MOS) or a hypothetical Erebus corridor MOS, which then relays 400MW to the onshore PCC.

3 Scenarios and Assumptions

3.1 Scenarios

For the purpose of this CBA, three connection scenarios have been compared:

1. 4 x 100MW wind farms connecting independently to onshore points of common coupling (PCCs) (Figure 1)
2. 4 x 100MW wind farms connecting to the PDZ MOS, with the PDZ MOS connecting 400MW to the onshore PCC (Figure 2)
3. 4 x 100MW wind farms connecting to the Erebus corridor MOS, with the Erebus Corridor MOS connecting 400MW to the onshore PCC (Figure 3)

The 4 x 100MW wind farms, the PDZ MOS option and the Erebus corridor MOS option have been modelled based on the technical assumptions shown in Table 1.

Table 1 – Zone and MOS Assumptions for CBA

Zone ID	Distance to onshore PCC (km)	Distance to Erebus corridor MOS (km)	Distance to PDZ MOS (km)	Voltage (kV)	Landfall	Independent Connection Point
1	54.5	14	23.5	66	Freshwater West	Pembroke
2	54.5	15	19.5	66	Freshwater West	Pembroke
3	54.5	15.5	9.5	66	Freshwater West	Pembroke
4	80.5	37	35.5	66	Yelland	Yelland
PDZ MOS	39	N/A	N/A	275	Freshwater West	Pembroke
Erebus corridor MOS	40.5	N/A	N/A	275	Freshwater West	Pembroke

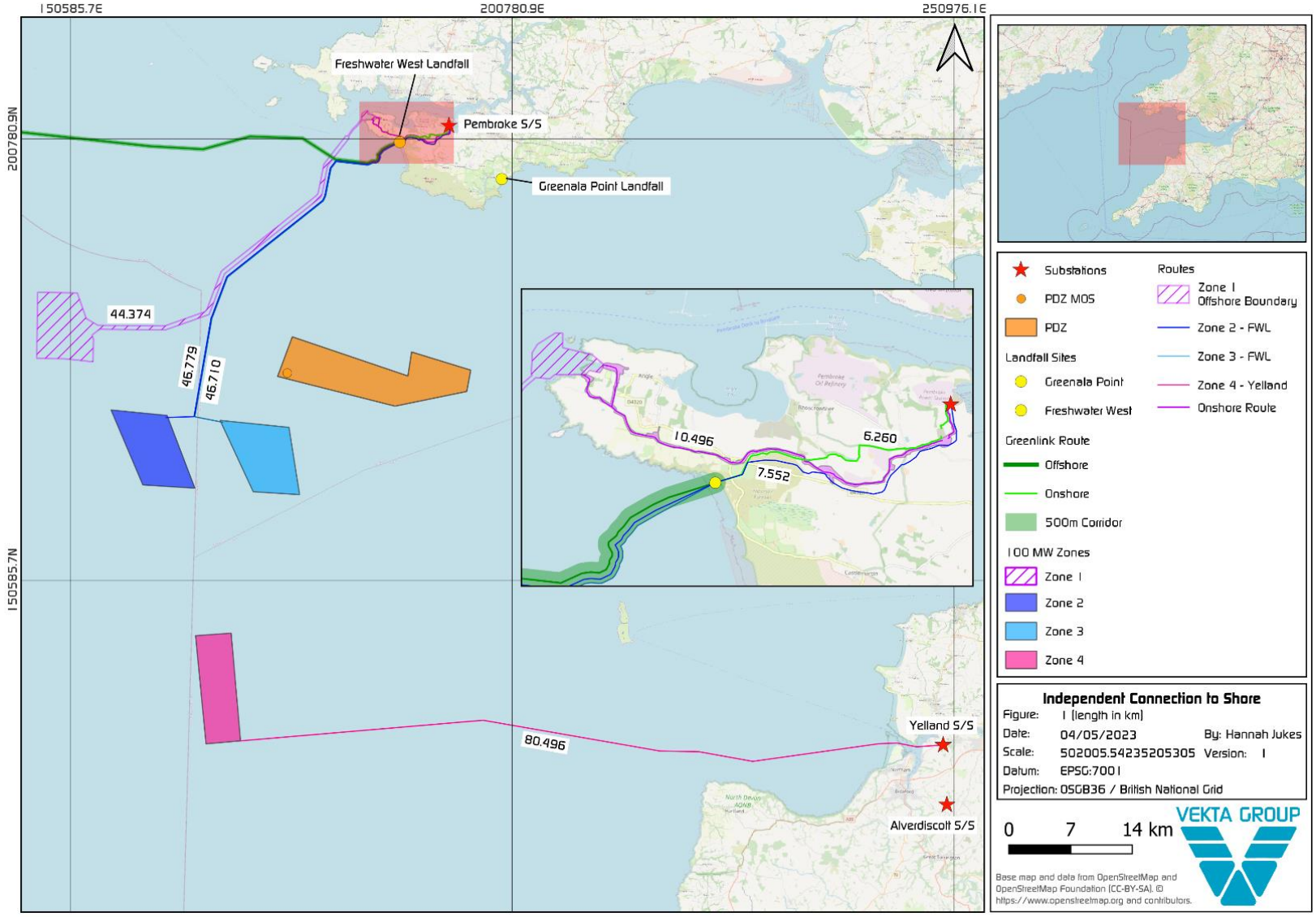

Figure 1 - Map of Zones and MOS with independent connections to shore

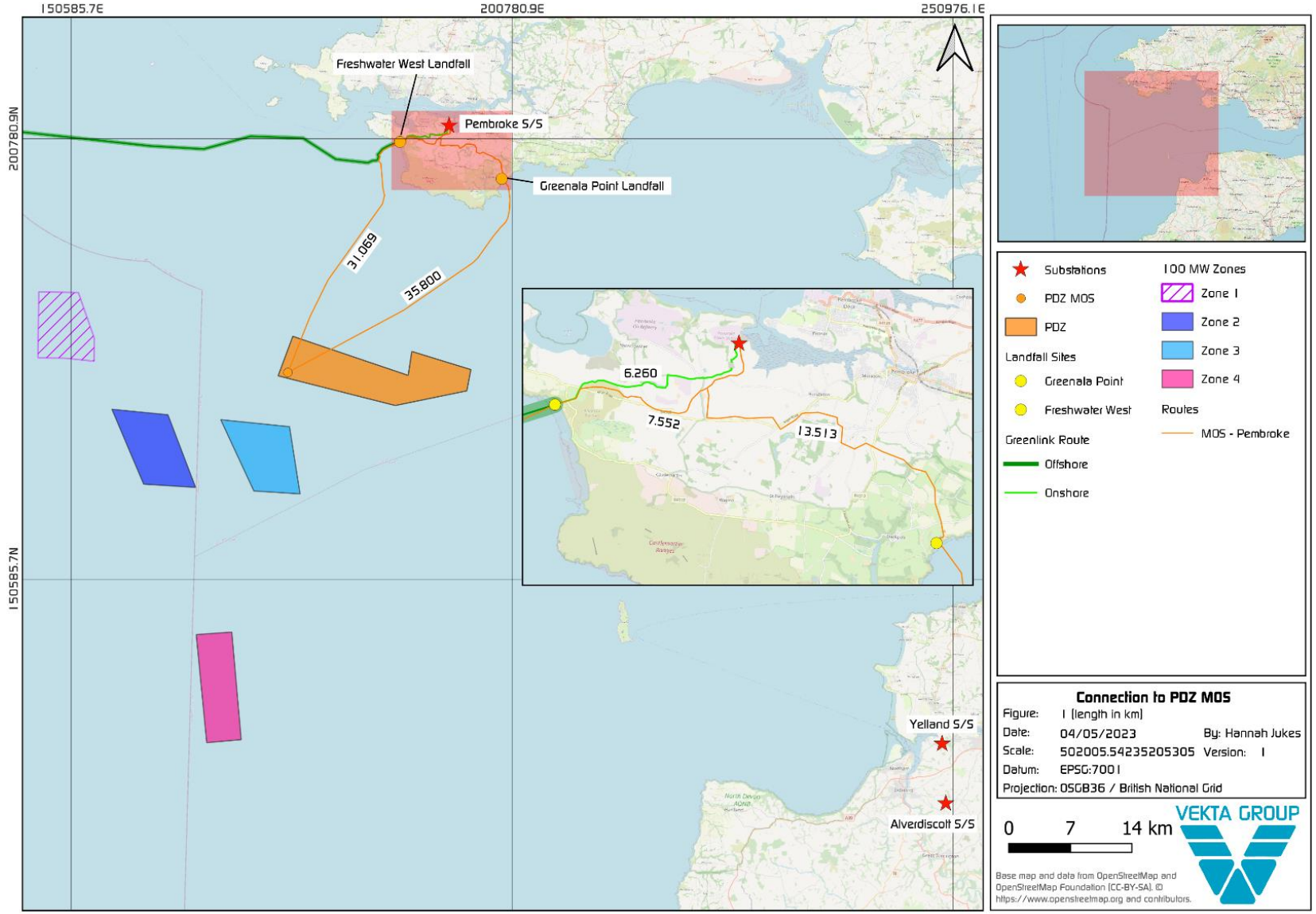

Figure 2 - Map of Zones and MOS with connections to PDZ MOS and landfalls

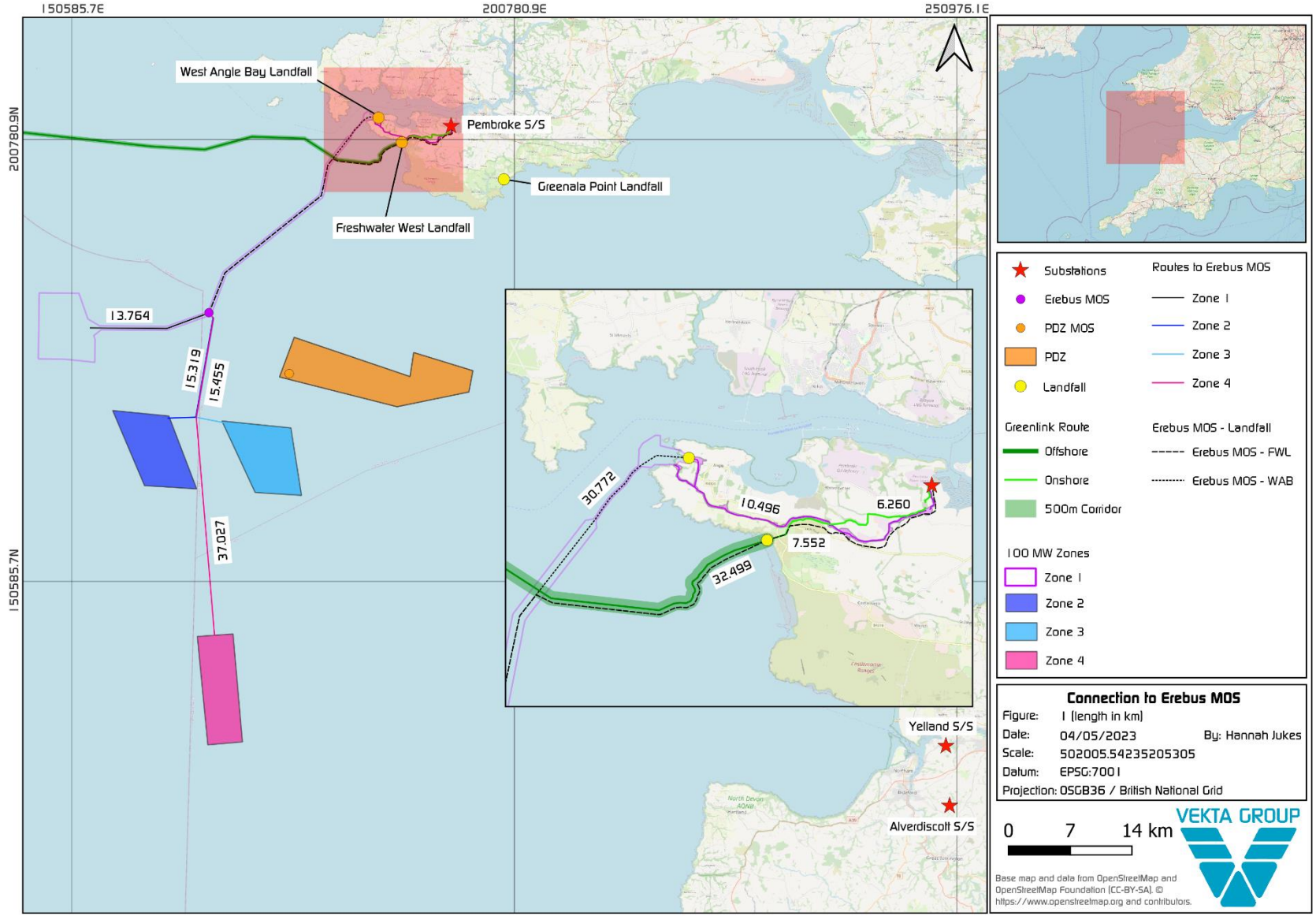

Figure 3 - Map of Zones and MOS with connections to Erebus corridor MOS and landfalls

3.2 Technical assumptions

Transmission Network Use of System (TNuoS) charges are the same for any project connecting to Pembroke. TNuoS charges are therefore not considered to be a differentiator between each PCC at this time because the regulatory and charging mechanism related to multi-user connection to an offshore transmission system has not been defined by the regulator.

The following assumptions were made for the 4 x 100MW independent connections scenarios:

Table 2 - Assumptions for 4 x 100MW Independent Connections

Criteria	Assumptions for 4 x 100MW Independent Connections
Cable supply	1000mm^2 66kV Al export cables. Pricing from recent RFQs (2023) and using Vekta Group in-house cable pricing tool. Supplied from EU OEM.
Cable installation	Proprietary cable installation planning tool using ERA5 regional metocean data. Boskalis Ndeavour installation vessel. Using simultaneous lay and bury. Cable supply pick-up from Rotterdam. Mobilisation/demobilisation at Eemshaven. Assumes HDD cost of £2.5M for each landing.
Onshore substation	Each Zone assumed to have single-circuit 66kV/400kV substation within 2km of PCC.
Offshore substation	Not applicable.
Land rights	Land lease rights and option agreements. Total annual leasing costs for cable route and onshore substation.
Onshore consent (DEVEX)	Assumed DEVEX cost for 4 years to achieve onshore consent, based on previous experience.
Offshore consent (DEVEX)	Assumed DEVEX cost for any surveys, engineering or consenting activities relating exclusively to export cable corridor.
Connection costs (non-contestable)	Any reinforcement works or National Grid substation works in relation to the PCC.
OPEX	HV services for maintaining electrical infrastructure only. Includes 1 cable failure for Zones 1, 2 & 4 and 2 cable failures for Zone 3. Does not include WTGs or O&M Base costs.
Electrical Losses (over 30 years)	Includes electrical losses of export cables (onshore and offshore) only based on a wind farm capacity factor of 56%, using generic 4 arrays x 6 x 16MW WTGs. Onshore transformer losses are not included. Power price is £90/MWh.

The following assumptions were made for the coordinated MOS solutions (both Erebus corridor MOS and PDZ MOS):

Table 3 – Assumptions for Coordinated MOS Solutions

Criteria	Assumptions for Coordinated MOS Solution
Cable supply	1000mm^2 Al 66kV export cable connecting each Zone to the MOS. 800mm^2 Al 275kV export cable from MOS to PCC. Pricing from recent RFQs (2023) and using Vekta Group in-house cable pricing tool. Supplied from EU OEM.
Cable installation	Proprietary cable installation planning tool using ERA5 regional metocean data. Cable installation assumption costs from each Zone to MOS does not include separate mob/demob costs due to assumption that the array cable vessel for each zone would absorb the mob/demob cost for the export cable. Boskalis Ndeavour installation vessel. Using simultaneous lay and bury. Cable supply pick-up from Rotterdam. Mobilisation/demobilisation at Eemshaven. Assumes HDD cost of £2.5M for landing.
Onshore substation	MOS assumed to have single-circuit 275kV/400kV substation within 2km of PCC.
Offshore substation	Includes supply and installation of topside and foundation.
Land rights	Land lease rights and option agreements. Total annual leasing costs for cable route and onshore substation. Larger land requirement assumed for onshore substation.
Onshore consent (devex)	Assumed DEVEX cost for 4 years to achieve onshore consent, based on previous experience.
Offshore consent (devex)	Assumed DEVEX cost for any surveys, engineering or consenting activities relating exclusively to export cable corridor.
Connection costs (non-contestable)	Any reinforcement works or National Grid substation works in relation to the PCC. Assumed onshore costs are higher for MOS due to increased connection capacity. For Zones 1-4 to MOS, includes cable pull in and termination and testing.
OPEX	HV services for electrical infrastructure from each site to MOS, full OPEX for MOS to PCC. MOS is an OFTO asset and fully maintained by said OFTO.
Electrical Losses (over 30 years)	Includes electrical losses of export cables (onshore and offshore) only based on a wind farm capacity factor of 56%, using generic 4 arrays x 6 x 16MW WTGs. Onshore transformer losses are not included. Power price is £90/MWh.

4 Independent radial connections

Costs in relation to connecting 4 x 100MW connections independently to respective independent onshore PCCs are detailed in Table 4 below.

Table 4 – Cost estimate for 4 x 100MW Zones to Onshore PCC

	4 x 100MW Zones to onshore PCC (£)				
Cost Item	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**TOTAL**
Cable supply	17,382,154	17,100,000	17,100,000	23,900,000	75,482,154
Cable installation	14,380,469	17,300,000	17,300,000	24,000,000	72,980,469
Onshore substation	15,000,000	15,000,000	15,000,000	15,000,000	60,000,000
Offshore substation	-	-	-	-	-
Land rights	10,000,000	10,000,000	10,000,000	10,000,000	40,000,000
Onshore consent (DEVEX)	10,000,000	10,000,000	10,000,000	10,000,000	40,000,000
Offshore consent (DEVEX)	10,000,000	10,000,000	10,000,000	15,000,000	45,000,000
Connection costs (non-contestable)	3,500,000	3,500,000	3,500,000	3,500,000	14,000,000
OPEX	31,000,000	31,000,000	31,000,000	35,000,000	128,000,000
Electrical Losses (over 30 years)	55,381,669	54,700,000	54,700,000	74,500,000	239,281,669
TOTAL	166,644,292	168,600,000	168,600,000	210,900,000	714,744,292

5 CBA for PDZ MOS

Figure 4 below shows a walkthrough of the costs from the initial baseline of 4 x 100MW zones connecting independently, to utilising the 400MW PDZ MOS as a coordinated solution.

Starting at the total CAPEX cost for 4 x 100MW independent radial generation projects, the 'decrease' in costs represent savings by working in a coordinated approach whilst the 'increase' in costs represent costs directly apportioned to the PDZ MOS infrastructure.

As can be noted from Figure 4 below the overall benefit when looking collectively at 400MW of generation, is that a coordinated approach has a cost saving of £90M.

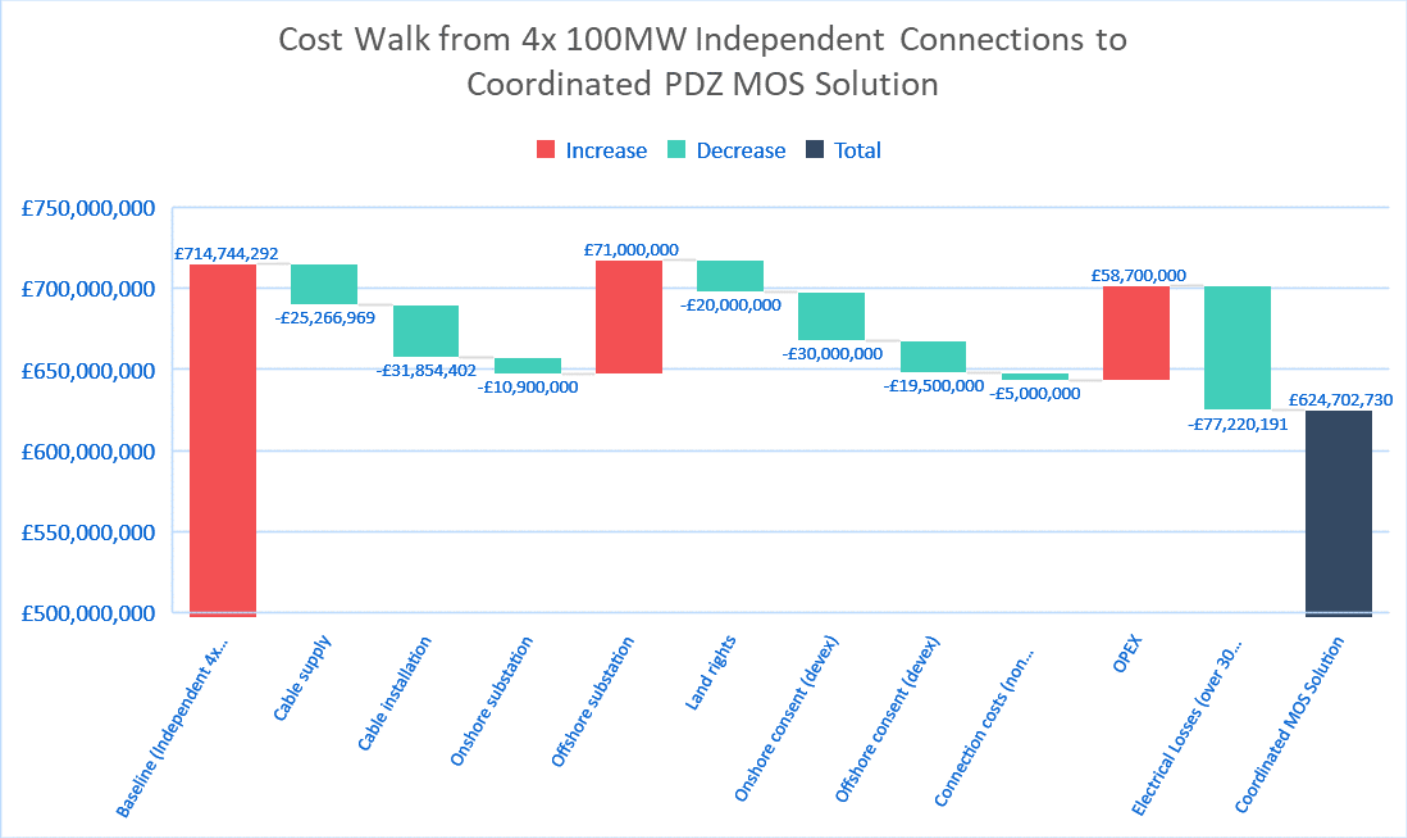

Figure 4 – Cost walk from 4 x 100MW Independent Connections to Coordinated PDZ MOS Solution

Figure 5 below shows a walkthrough of a single 100MW project (Zone 1) connecting independently to an onshore PCC, to connecting to the PDZ MOS as part of a coordinated approach.

Starting at the total CAPEX cost for single 100MW independent radial generation project, the 'decrease' in costs represent savings by connecting to the PDZ MOS.

As can be noted from Figure 5 below the overall benefit, when considering a single 100MW generation project, is that a coordinated approach has a cost saving of £105.5m. It should be noted that this is the direct CAPEX and OPEX cost saving by the individual generation project and does not include the cost of PDZ MOS infrastructure or costs for connecting the MOS to the PCC. It is also not based on a financial model being produced for each individual project.

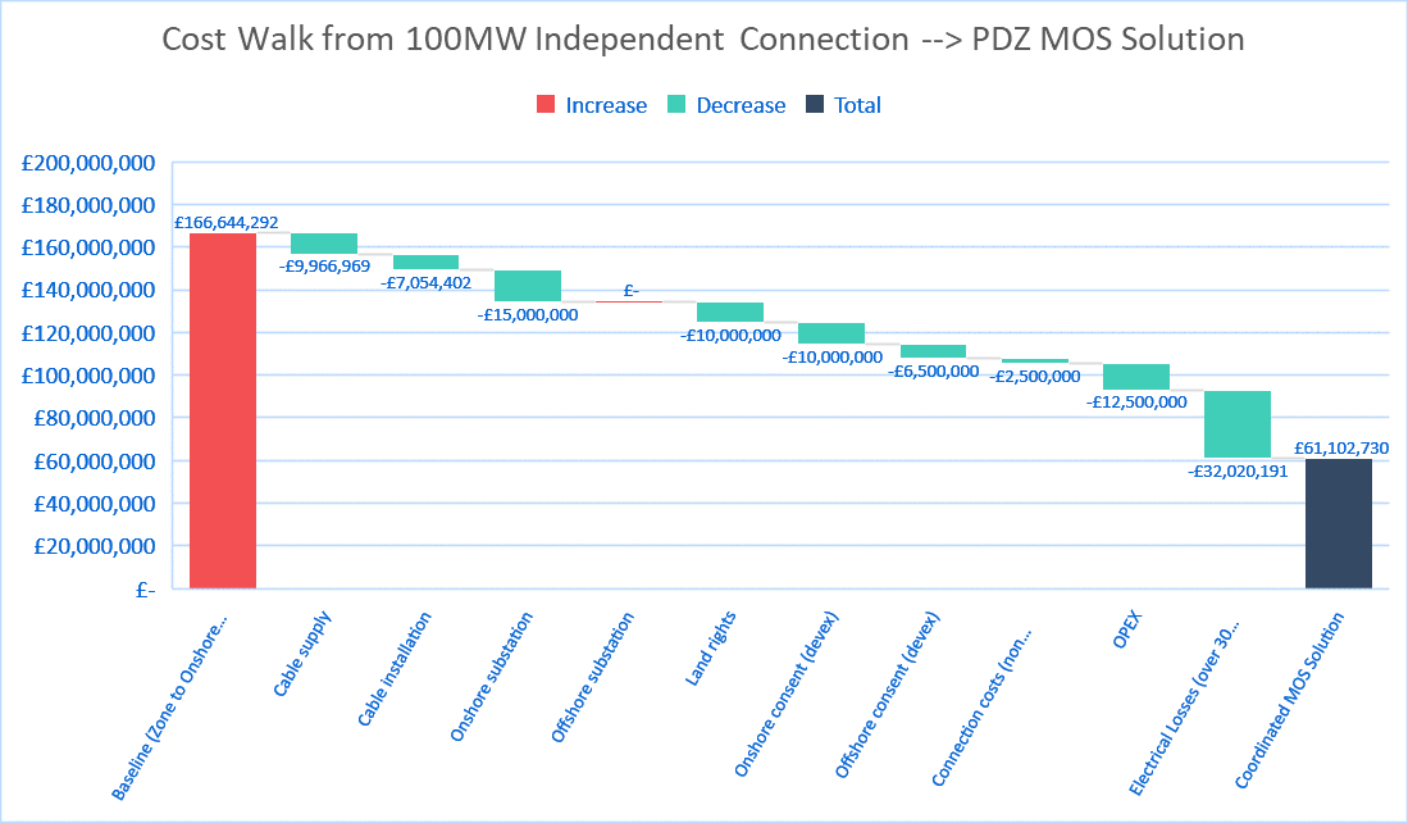

Figure 5 – Cost Walk from 100MW Independent Connection (Zone 1) to PDZ MOS Solution

Costs in relation to 4 x 100MW connections to the PDZ MOS and then the MOS connecting to the onshore PCC are shown in Table 5 below.

Table 5 – Cost estimate for PDZ MOS Solution

Cost Item	4 x 100MW Zones to PDZ MOS (£)				400MW MOS to PCC (£)	TOTAL (£)
	Zone 1	Zone 2	Zone 3	Zone 4	PDZ MOS	
Cable supply	7,415,185	6,200,000	3,000,000	11,300,000	22,300,000	**50,215,185**
Cable installation	7,326,067	6,100,000	2,900,000	11,100,000	13,700,000	**41,126,067**
Onshore substation	-	-	-	-	49,100,000	**49,100,000**
Offshore substation	-	-	-	-	71,000,000	**71,000,000**
Land rights	-	-	-	-	20,000,000	**20,000,000**
Onshore consent (DEVEX)	-	-	-	-	10,000,000	**10,000,000**
Offshore consent (DEVEX)	3,500,000	3,500,000	3,500,000	5,000,000	10,000,000	**25,500,000**
Connection costs (non-contestable)	1,000,000	1,000,000	1,000,000	1,000,000	5,000,000	**9,000,000**
OPEX	18,500,000	18,500,000	18,500,000	18,500,000	112,700,000	**186,700,000**
Electrical Losses (over 30 years)	23,361,478	19,600,000	9,700,000	34,600,000	74,800,000	**162,061,478**
TOTAL	**61,102,730**	**54,900,000**	**38,600,000**	**81,500,000**	**388,600,000**	**624,702,730**

6 CBA for MOS in Erebus Corridor

Figure 6 below shows a walkthrough of the costs from the initial baseline of 4 x 100MW zones connecting independently, to utilising the hypothetical 400MW Erebus corridor MOS as a coordinated solution.

Starting at the total CAPEX cost for 4 x 100MW independent radial generation projects, the 'decrease' in costs represent savings by working in a coordinated approach whilst the 'increase' in costs represent costs directly apportioned to the Erebus corridor MOS infrastructure.

As can be noted from Figure 6 below the overall benefit when looking collectively at 400MW of generation, is that a coordinated approach has a cost saving of £92.4M.

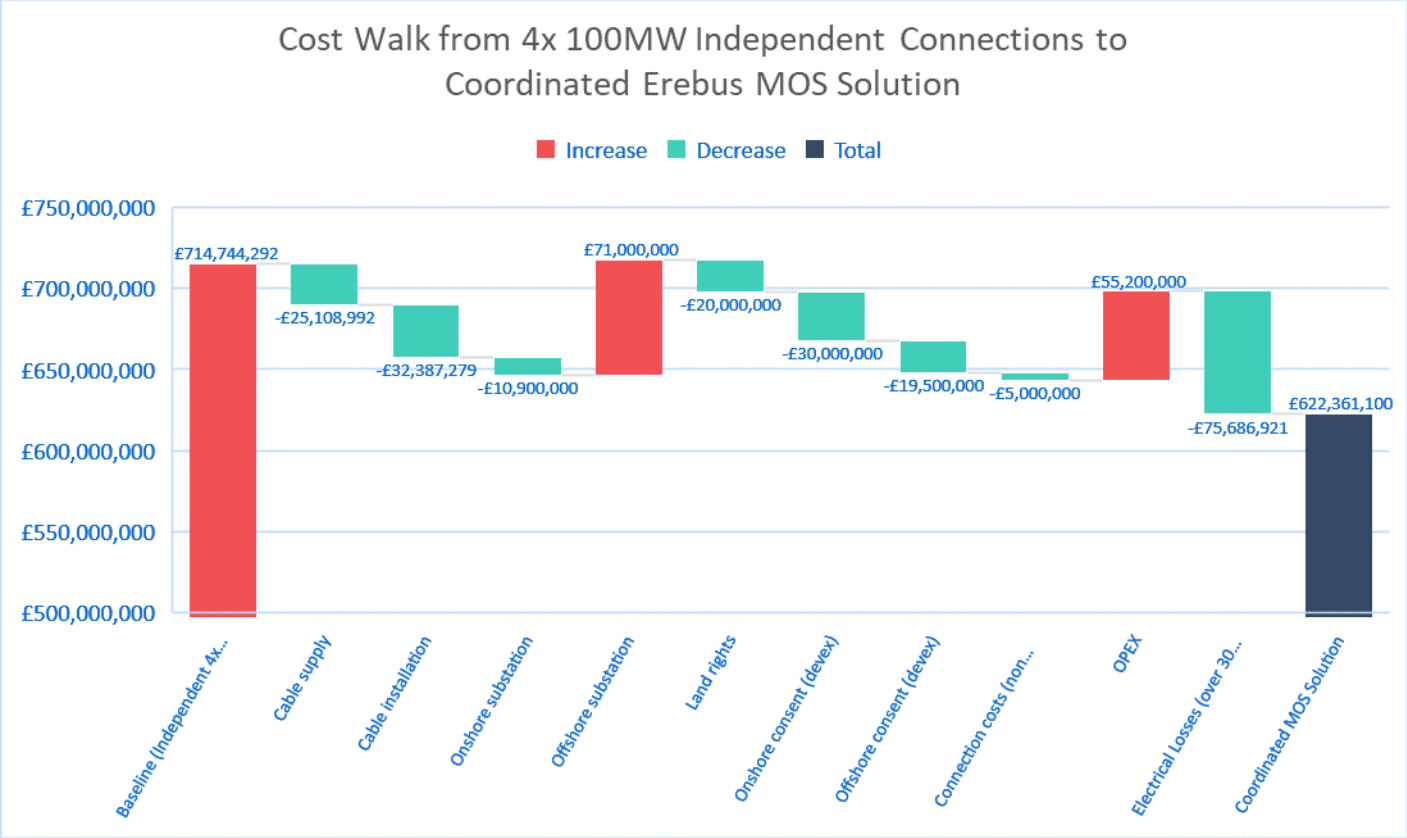

Figure 6 – Cost walk from 4 x 100MW Independent Connections to Coordinated Erebus corridor MOS Solution

Figure 7 below shows a walkthrough of a single 100MW project (Zone 1) connecting independently to an onshore PCC, to connecting to the hypothetical Erebus corridor MOS as part of a coordinated approach.

Starting at the total CAPEX cost for single 100MW independent radial generation project, the 'decrease' in costs represent savings by connecting to the PDZ MOS.

As can be noted from Figure 7 below the overall benefit, when considering a single 100MW generation project, is that a coordinated approach has a cost saving of £123.5m. It should be noted that this is the direct CAPEX and OPEX cost saving by the individual generation project and does not include the cost of PDZ MOS infrastructure or costs for connecting the MOS to the PCC. It is also not based on a financial model being produced for each individual project.

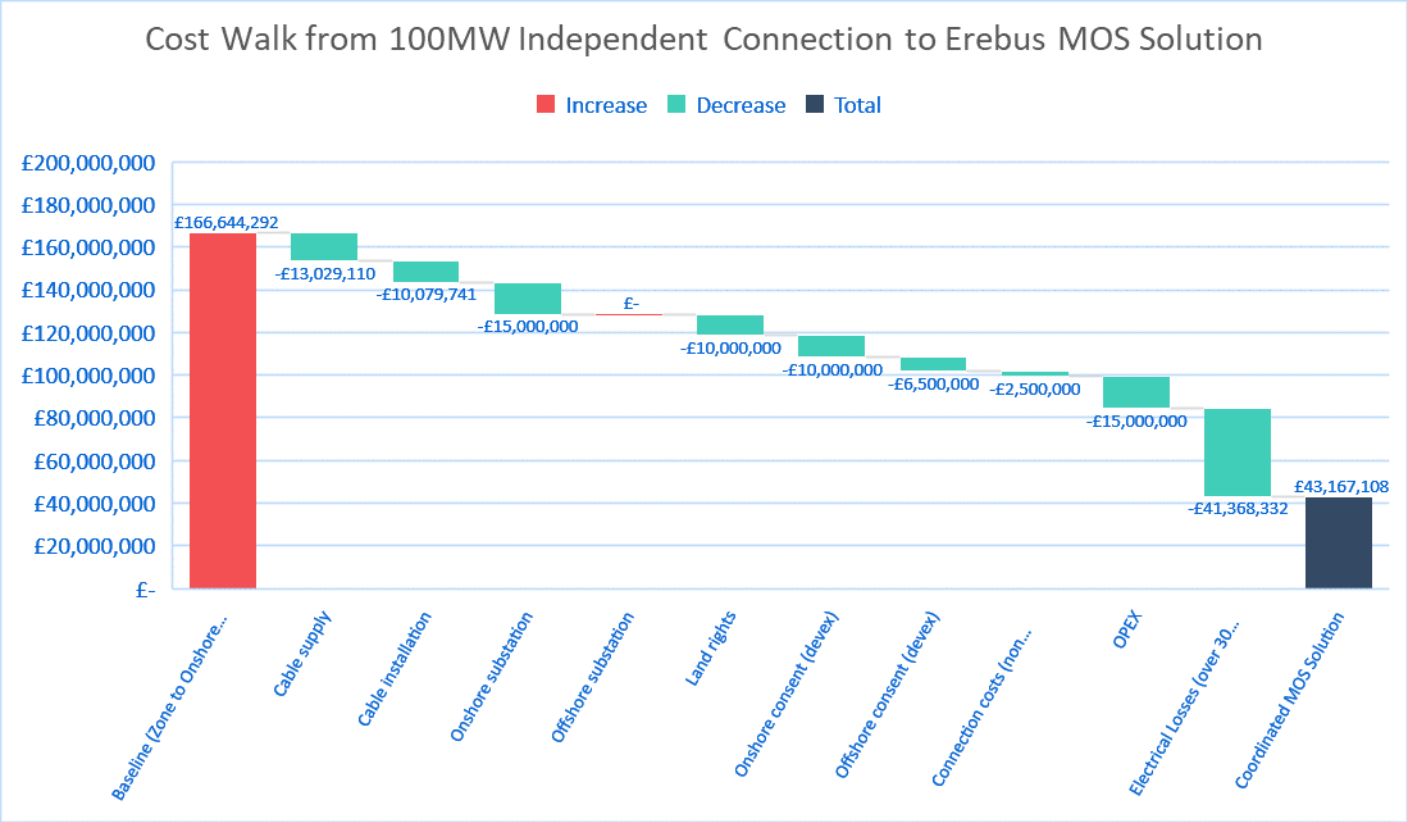

Figure 7 – Cost Walk from 100MW Independent Connection (Zone 1) to Erebus corridor MOS Solution

Cost in relation to 4 x 100MW connections to the Erebus corridor MOS, then the MOS connecting to the onshore PCC are shown in Table 6 below:

Table 6 – Cost estimate for Erebus corridor MOS Solution

Cost Item	4 x 100MW Zones to Erebus corridor MOS (£)				400MW MOS to PCC (£)	TOTAL (£)
	Zone 1	Zone 2	Zone 3	Zone 4	Erebus corridor MOS	
Cable supply	4,353,044	4,893,422	4,893,422	11,678,166	24,555,110	**50,373,163**
Cable installation	4,300,728	4,834,611	4,834,611	11,537,814	15,085,426	**40,593,190**
Onshore substation	-	-	-	-	49,100,000	**49,100,000**
Offshore substation	-	-	-	-	71,000,000	**71,000,000**
Land rights	-	-	-	-	20,000,000	**20,000,000**
Onshore consent (DEVEX)	-	-	-	-	10,000,000	**10,000,000**
Offshore consent (DEVEX)	3,500,000	3,500,000	3,500,000	5,000,000	10,000,000	**25,500,000**
Connection costs (non-contestable)	1,000,000	1,000,000	1,000,000	1,000,000	5,000,000	**9,000,000**
OPEX	16,000,000	16,000,000	20,000,000	18,500,000	112,700,000	**183,200,000**
Electrical Losses (over 30 years)	14,013,337	15,690,529	15,690,529	35,836,129	82,364,224	**163,594,748**
TOTAL	**43,167,108**	**45,918,561**	**49,918,561**	**83,552,109**	**399,804,760**	**622,361,100**

7 Conclusion and Recommendations

There are several key outcomes of the CBA, each of which demonstrate that the CAPEX and OPEX costs of a multi-project offshore connection are consistently lower than if each 100MW project were to connect independently to an onshore PCC:

7.1 PDZ MOS

- The cost saving between a coordinated 400W PDZ MOS solution and 4 x 100MW independent projects is £90M.
- The cost saving for each 100MW zone ranges from £105.5-130M, relative to DPO location. This does not include the cost of connecting the MOS to the PCC, nor the MOS infrastructure costs.

7.2 Erebus corridor MOS

- The cost saving between a coordinated 400W Erebus corridor MOS solution and 4 x 100MW independent projects is £92.4M.
- The cost saving for each 100MW zone ranges from £118.7-127.4M, relative to DPO location. This does not include the cost of connecting the MOS to the PCC, nor the MOS infrastructure costs.

It is recommended that further investigation is conducted to obtain a more detailed (higher-class) level of pricing information from the supply chain. This is to verify the cost estimates presented in this report, which are currently class 3 or 4, depending on the scope item (e.g. cables, substructures and substation).

The coordinated MOS approach requires the initial user/developer (the 100MW demonstrator projects) to make an anticipatory investment to develop the primary common infrastructure that will then be shared with future users to facilitate their connection. The later user(s) will then fund the further infrastructure required for their development. The initial user recovers its additional design and construction costs from the OFTO auction and ongoing liabilities, securities and risk sit with the consumer until the later user connects.

It is worth noting that there is no discernible cost or risk-benefit to proceeding with the option to develop a MOS within the Erebus consented cable corridor (Erebus corridor MOS, Figure 3). The only exception to this is that the cable route and onshore substation location is already consented for the Erebus project. Nonetheless, the project consent would still require a variation for the substation design and also the offshore consent to accommodate a MOS. The PDZ has already been granted a seabed lease and is designed for demonstrator projects or an MOS platform and therefore it is strongly recommended that CSP does not proceed with relocating the MOS to the Erebus cable corridor as it is not practicable. Without written consent of the Erebus project, it is not recommended that an Erebus corridor MOS be demonstrated to external stakeholders at this stage.

Furthermore, given that the Erebus project (Zone 1 in this addendum) is significantly more advanced than the other 100MW demonstrator projects in the region, it is highly unlikely that they would be willing to amend their existing route to market without significant compensation and guarantees on programme risk and anticipatory investment. Any perceived cost savings shown in this addendum for the Erebus project connecting to an MOS rather than independently could quickly be negated by the project around DEVEX delay costs and compensation.

In conclusion, this addendum has demonstrated that adopting a coordinated approach as opposed to 4 x 100MW independent radial connections, could save up to £90M (12.6%) for the PDZ MOS option, or £92.4M (12.9%) for the Erebus corridor MOS option, in principle. However, the below caveats should be considered:

- This saving is subject to an anticipatory investment / commercial model, neither of which have been investigated as part of this addendum.
- A PDZ MOS is more feasible than an Erebus corridor MOS due to the existing consents in place and the development stage of the Erebus project.
- The Erebus project may be too advanced in the development process to re-consider their route to market, therefore they are unlikely to consider connecting to a MOS.

8 Anticipatory investment

Anticipatory investment has been considered for both scenarios, PDZ MOS and Erebus corridor MOS as presented within this report.

8.1 Approach

Following a similar approach commissioned by Ofgem, capital expenditure (CAPEX) estimates for the independent and coordinated scenarios have been prepared and presented in Sections 5 and 6 – based on two delivery approaches:

- Independent (Referred to as 'Counterfactual' by Ofgem report)
- Coordinated (Referred to as 'Integrated' by Ofgem report)

'Independent' is the current and most common approach when developing new infrastructure for offshore wind farms. This involves the development of separate single users with radial connections.

'Coordinated' is an approach with more than one user sharing a common offshore transmission system. Delivery models are being developed for this approach to provide greater clarity. Where collaboration is between a known and potential future user, who is entering the market at different auction rounds, Ofgem has set out the process for that to be delivered via their minded to decision on Anticipatory Investment (AI).

This approach requires the Initial User (IU) to make an anticipatory investment to develop the primary common infrastructure that will then be shared with future users to facilitate their connection. The Later User(s) (LU) will then fund the further infrastructure required for their development. The IU recovers its additional design and construction costs from the OFTO auction and ongoing liabilities, securities and risk sit with the consumer until the later user connects.

For developers who enter the same round, Ofgem are expecting them to work collaboratively on a commercial solution. However, their approach does not factor in the developing leasing round strategy to allow the delivery of floating offshore wind projects in phases. These could be subject to future regulatory amendments to enable delivery.

For this report, the assumption is that the AI cost gap and AI risk will reside with the consumer as per Ofgem's current decision and has used the terms Initial User and Later User to describe the parties collaborating.

8.2 PDZ MOS

The anticipatory investment for the scenario of the MOS being located within the PDZ is presented below.

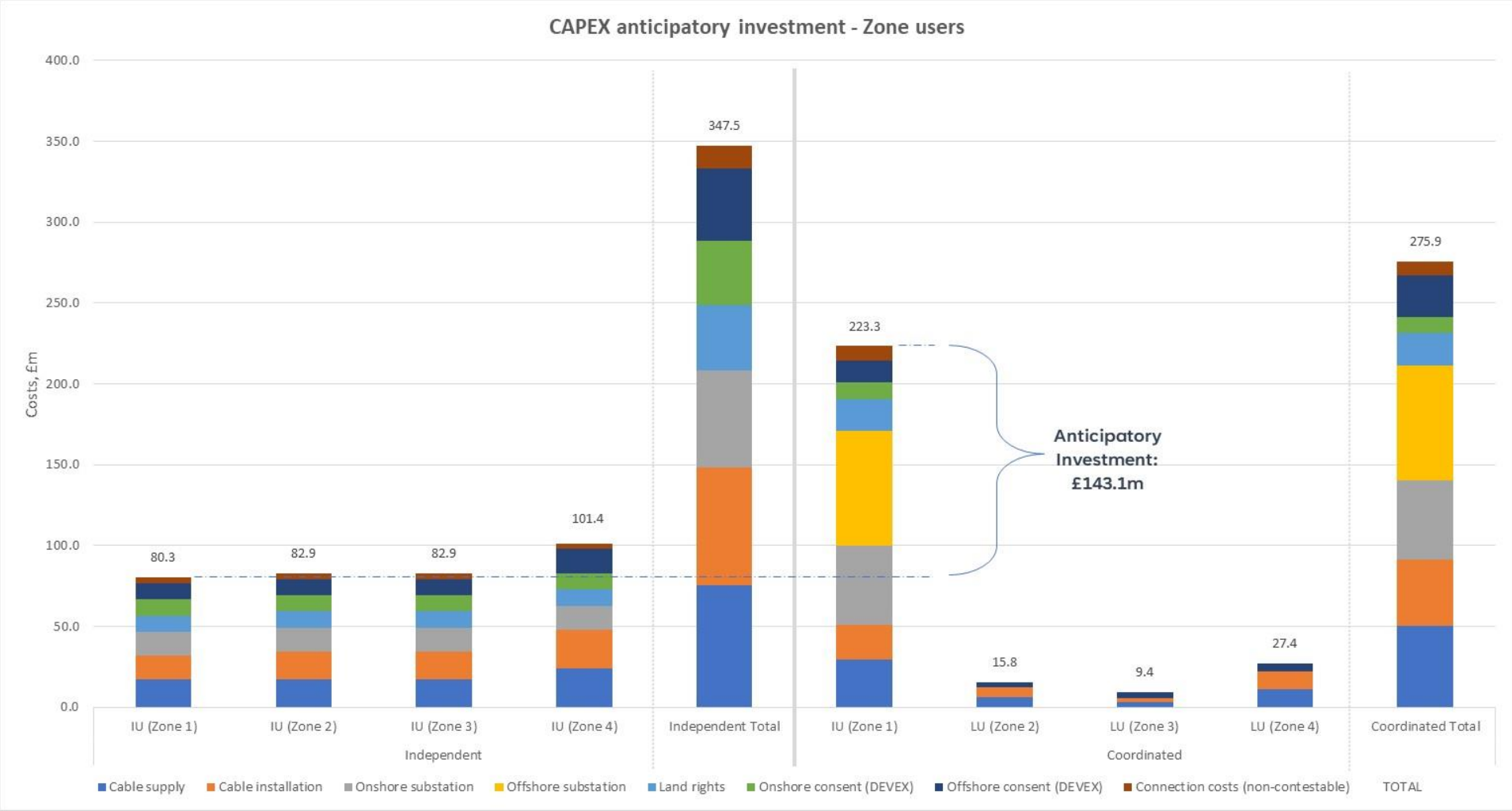

Figure 8 – Anticipatory investment for MOS within PDZ

Table 7 – CAPEX estimates for AI by zone users with MOS in PDZ

CAPEX estimates	Independent					Coordinated				
Cost Item	**IU** (Zone 1) £m	**IU** (Zone 2) £m	**IU** (Zone 3) £m	**IU** (Zone 4) £m	**Independent Total** £m	**IU** (Zone 1) £m	**LU** (Zone 2) £m	**LU** (Zone 3) £m	**LU** (Zone 4) £m	**Coordinated Total** £m
Cable supply	17.4	17.1	17.1	23.9	75.5	29.7	6.2	3.0	11.3	50.2
Cable installation	14.4	17.3	17.3	24.0	73.0	21.0	6.1	2.9	11.1	41.1
Onshore substation	15.0	15.0	15.0	15.0	60.0	49.1	0.0	0.0	0.0	49.1
Offshore substation	0.0	0.0	0.0	0.0	0.0	71.0	0.0	0.0	0.0	71.0
Land rights	10.0	10.0	10.0	10.0	40.0	20.0	0.0	0.0	0.0	20.0
Onshore consent (DEVEX)	10.0	10.0	10.0	10.0	40.0	10.0	0.0	0.0	0.0	10.0
Offshore consent (DEVEX)	10.0	10.0	10.0	15.0	45.0	13.5	3.5	3.5	5.0	25.5
Connection costs (non-contestable)	3.5	3.5	3.5	3.5	14.0	9.0	-	-	-	9.0
TOTAL	**80.3**	**82.9**	**82.9**	**101.4**	**347.5**	**223.3**	**15.8**	**9.4**	**27.4**	**275.9**

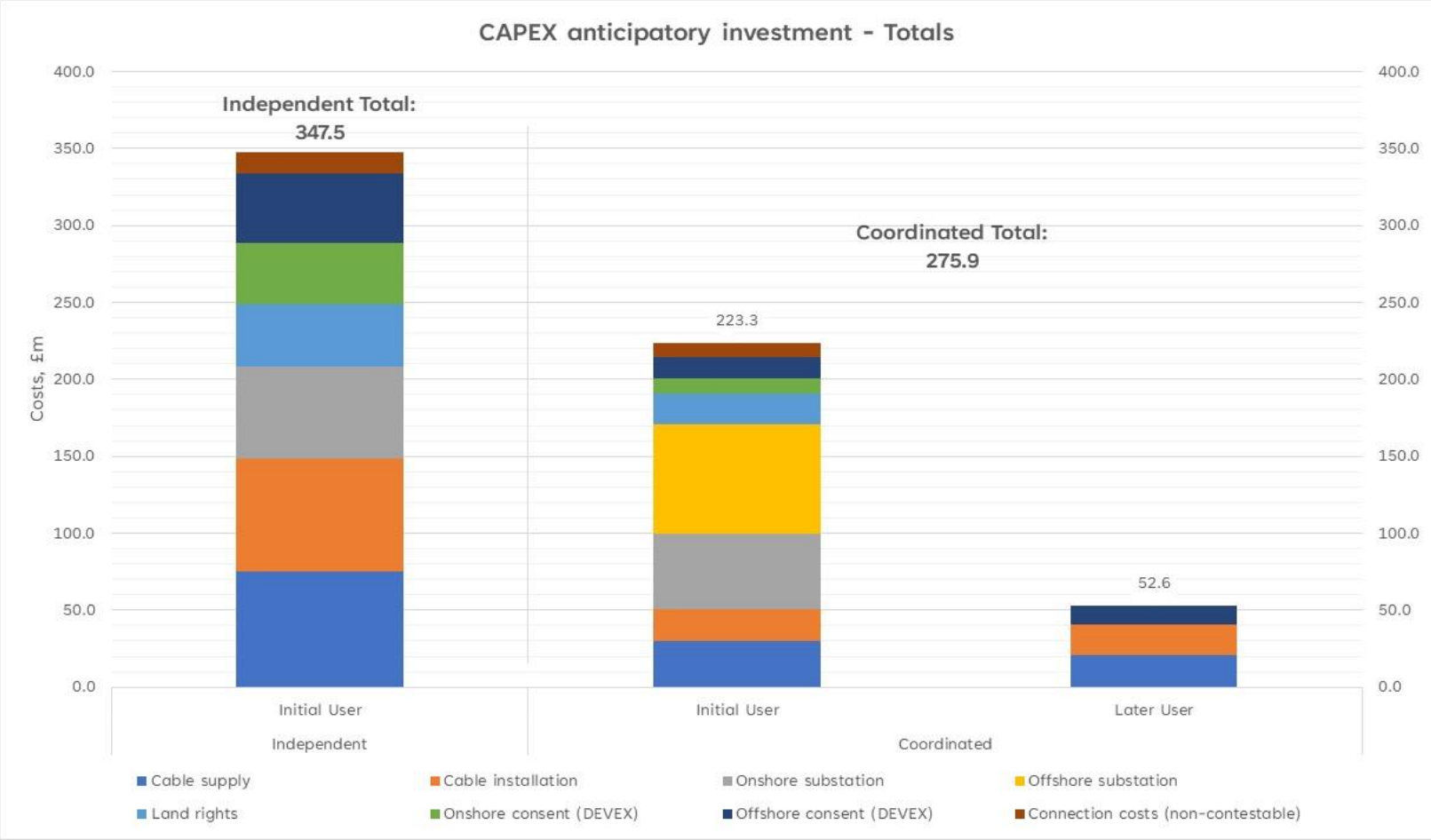

Figure 9 - Anticipatory investment totals for MOS within PDZ

Table 8 – CAPEX estimates for AI totals with MOS in PDZ

CAPEX estimates	**Independent**	**Coordinated**	
Cost Item	Initial User, £m	Initial User, £m	Later User, £m
Cable supply	75.5	29.7	20.5
Cable installation	73.0	21.0	20.1
Onshore substation	60.0	49.1	0.0
Offshore substation	0.0	71.0	0.0
Land rights	40.0	20.0	0.0
Onshore consent (DEVEX)	40.0	10.0	0.0
Offshore consent (DEVEX)	45.0	13.5	12.0
Connection costs (non-contestable)	14.0	9.0	0.0
Subtotal, £m	**347.5**	**223.3**	**52.6**
Total, £m	**347.5**	**275.9**	

8.3 Erebus corridor MOS

The anticipatory investment for the scenario of the MOS being located within the Erebus consented corridor is presented below.

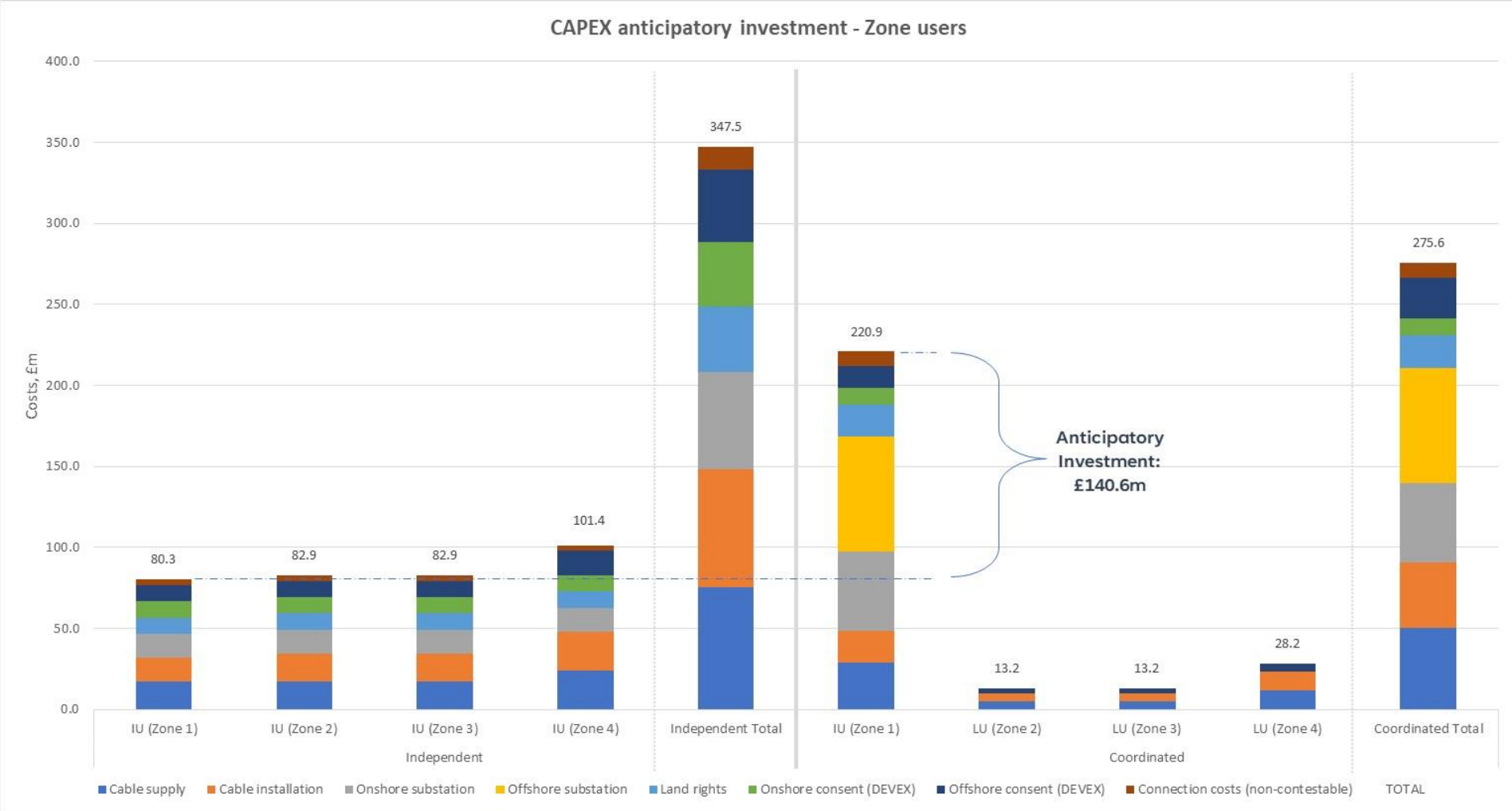

Figure 10 – Anticipatory investment for MOS in Erebus cable corridor

Table 9 – CAPEX estimates for AI by zone users with MOS in Erebus cable corridor

CAPEX estimates	Independent					Coordinated				
Cost Item	**IU** (Zone 1) £m	**IU** (Zone 2) £m	**IU** (Zone 3) £m	**IU** (Zone 4) £m	**Independent Total** £m	**IU** (Zone 1) £m	**LU** (Zone 2) £m	**LU** (Zone 3) £m	**LU** (Zone 4) £m	**Coordinated Total** £m
Cable supply	17.4	17.1	17.1	23.9	75.5	28.9	4.9	3.9	11.7	50.4
Cable installation	14.4	17.3	17.3	24.0	73.0	19.4	4.8	4.8	11.5	40.6
Onshore substation	15.0	15.0	15.0	15.0	60.0	49.1	0.0	0.0	0.0	49.1
Offshore substation	0.0	0.0	0.0	0.0	0.0	71.0	0.0	0.0	0.0	71.0
Land rights	10.0	10.0	10.0	10.0	40.0	20.0	0.0	0.0	0.0	20.0
Onshore consent (DEVEX)	10.0	10.0	10.0	10.0	40.0	10.0	0.0	0.0	0.0	10.0
Offshore consent (DEVEX)	10.0	10.0	10.0	15.0	45.0	13.5	3.5	3.5	5.0	25.5
Connection costs (non-contestable)	3.5	3.5	3.5	3.5	14.0	9.0	-	-	-	9.0
TOTAL	**80.3**	**82.9**	**82.9**	**101.4**	**347.5**	**220.9**	**13.2**	**13.2**	**28.2**	**275.6**

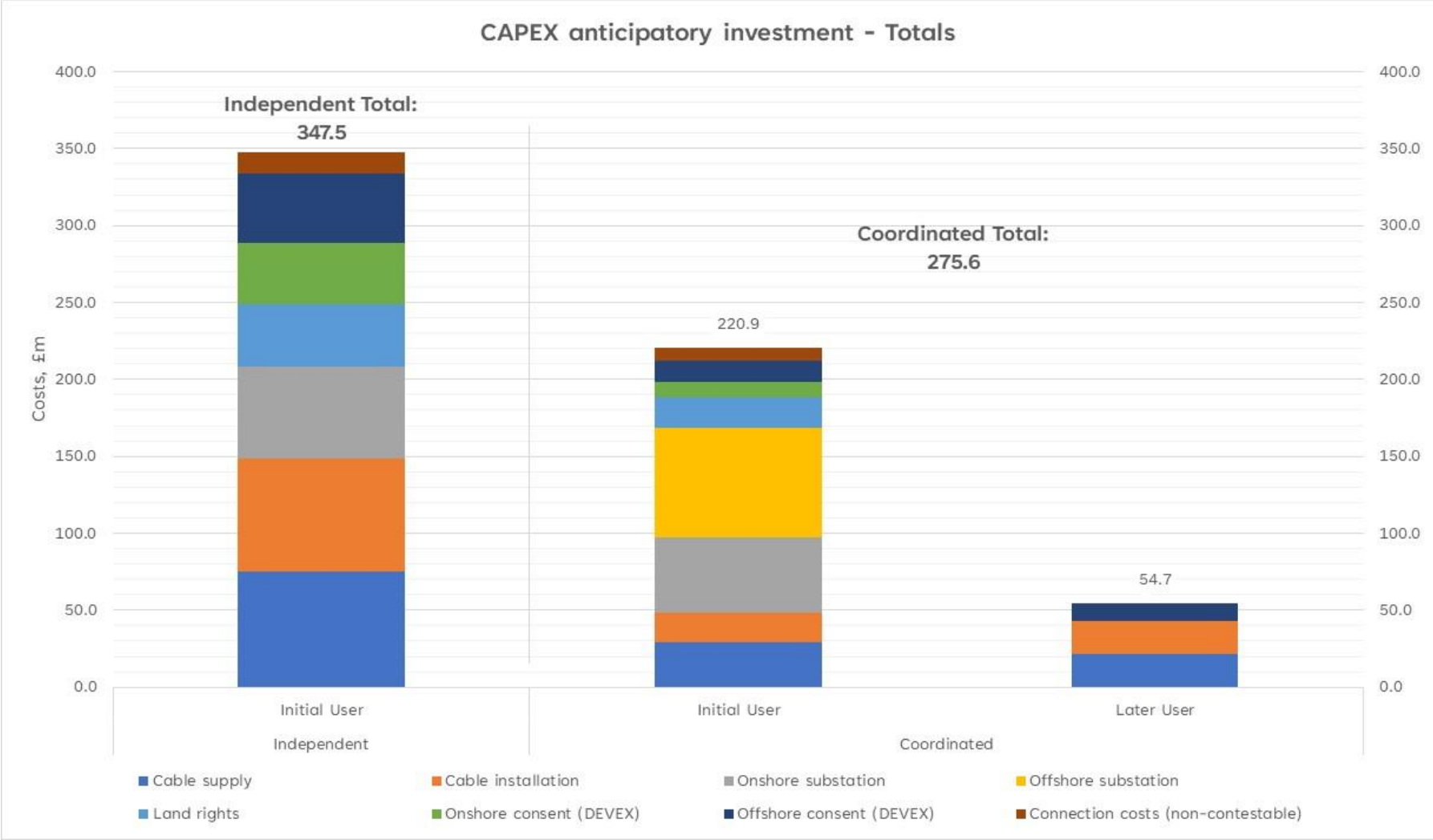

Figure 11 - Anticipatory investment totals for MOS within Erebus cable corridor

Table 10 – CAPEX estimates for AI totals with MOS in Erebus cable corridor

CAPEX estimates	**Independent**	**Coordinated**	
Cost Item	Initial User, £m	Initial User, £m	Later User, £m
Cable supply	75.5	28.9	21.5
Cable installation	73.0	19.4	21.2
Onshore substation	60.0	49.1	0.0
Offshore substation	0.0	71.0	0.0
Land rights	40.0	20.0	0.0
Onshore consent (DEVEX)	40.0	10.0	0.0
Offshore consent (DEVEX)	45.0	13.5	12.0
Connection costs (non-contestable)	14.0	9.0	0.0
Subtotal, £m	**347.5**	**220.9**	**54.7**
Total, £m	**347.5**	**275.6**	

9 References

[1] Apollo, 395-003-GRL-RPT-0003-0 PDZ 400MW MOS Concept Study Report, 2023.

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