RAS Carbon Abatement Report

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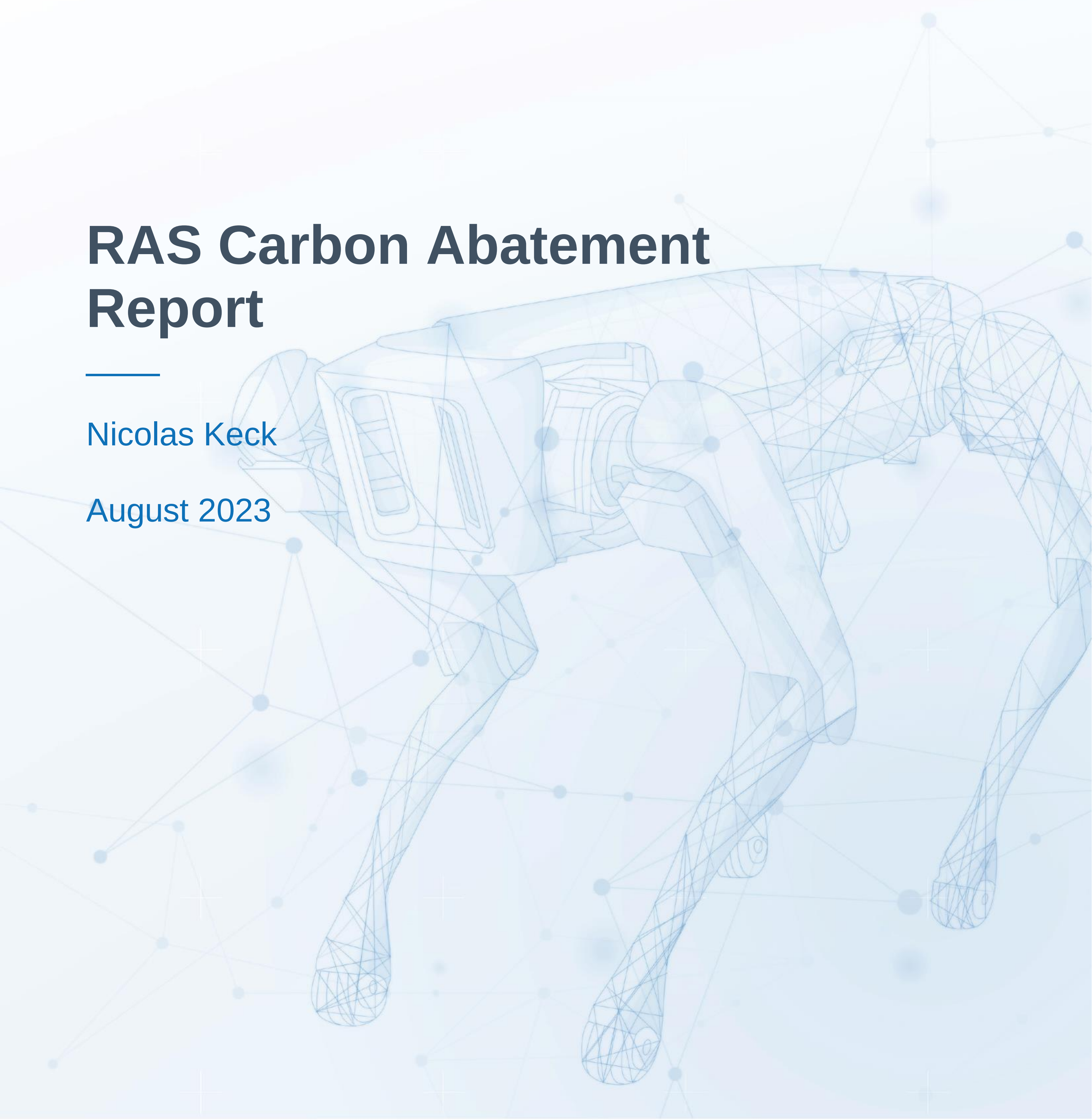

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Glossary of Terms

Asset	Any Offshore Rig or Installation (Generally Manned)
AUV	Automated Underwater Vehicle
BAU	Business as Usual
BEIS	Department for Business, Energy & Industrial Strategy
BVLOS	Beyond Visual Line of Sight
DESNZ	Department for Energy Security and Net Zero
DP	Dynamic Positioning
ECO	Best Vessel Speed with Economic Fuel Consumption
EEMS	Environmental and Emissions Monitoring System
LTO	Landing and Takeoff
NUF/NUI	Normally Unmanned Facility/Installation
NZTC	Net Zero Technology Centre
MGO	Marine Gas Oil
O&G	Oil and Gas
OEUK	Offshore Energies UK
OIM	Offshore Installation Manager
OLTER	Offshore Low Touch Energy RAS
POB	Personnel on Board
PSV	Platform Supply Vessel
RAS	Robotics and Autonomous Systems
SPE	Society of Petroleum Engineers
UKCS	United Kingdom Continental Shelf

Executive Summary

1 OLTER Introduction

The Offshore Low Touch Energy Robotics and Autonomous Systems (OLTER) is one of seven projects currently underway through the Net Zero Technology Transition Programme (NZTTP), to transform the North Sea energy system with a focus on emissions reduction. NZTTP was formed in 2021, when a total of £16.5 million was awarded to NZTC by UK Government to accelerate a range of energy transition projects that will help deliver Scotland's net-zero economy.

OLTER aims to deliver a Robotics and Autonomous Systems (RAS) service to scale and commercialize robotics for use in the offshore energy environment. RAS stand to deliver operational efficiency, environmental, and health and safety benefits, by substituting activities traditionally undertaken through human interventions primarily in operations and maintenance. RAS commercialization is currently hindered by a variety of market barriers, of which OLTER's RAS service is designed to mitigate, increasing RAS penetration in the offshore energy market. More information about the OLTER project can be found on the OLTER website.

2 Report justification and goals

A key environmental benefit of the deployment of RAS is carbon abatement. By reducing the frequency personnel need to be flown offshore, by using autonomous vessels to ship cargo and inspect subsea equipment, by flying urgent equipment using autonomous air vehicles instead of helicopter, and through application of many more types of RAS, the carbon and methane emissions of offshore activity can be reduced significantly. An issue both RAS developers and offshore energy operators face, however, is calculating what the potential emissions reduction of deploying a RAS system across several assets may be. This is not a trivial issue, when reducing the amount of personnel deployed offshore for example, it is insufficient to simply say that the helicopter transport emissions are reduced by a fraction of the capacity of the helicopter; the helicopter will likely fly out at full capacity regardless. As such, there is need among operators for a number of reference figures in order to properly account for the carbon abatement provided by deployment of existing and future RAS; discussions with industry personnel determined that thorough carbon calculations are currently a major gap in RAS business cases presented to operators for technology approval.

The purpose of this report and its associated tool, therefore, is to assist operators by considering a variety of emissions calculation methodologies, and to then recommend and justify the most appropriate. The approach utilizes figures from reliable academic sources, UK government reports, and averages provided by major offshore energy operators. Individual source choices are justified later within this report, but sources were chosen specifically to be as trustworthy as possible. These sources are reference when applicable throughout this report.

According to the London Economics' 2021 report for the Department for Business, Energy & Industrial Strategy, 39% of tasks could be automated within the offshore energy industry [1]. As such, the final goal of this report was to provide a figure of the total expected carbon abatement possible given OLTER intervention in the RAS space; something that has to date not been provided. A tabulated summary of key report findings can be seen in table A-1.

3 Report methodology

To ensure the accuracy, clarity, and credibility of this report, its results, and its associated calculator (which may also be found on OLTER's website), some key decisions and assumptions have been made in regards to the methodology. Firstly, estimates within this report will always err on the more conservative side when calculating abatement. This is to ensure that results from this report do not "over-promise" to operators, especially if these methodologies are used on a wider industry scale. As such, real abatement may be higher than is calculated. Another goal of this report is to provide methodologies which are as adaptable to future RAS development as possible. In many cases, this has been performed by abstracting the actual RAS system and instead focusing on impacts the system will have BAU operation; this was performed in such a way as to not significantly impact the accuracy of report results. In cases where a methodology could not be provided for specific RAS use cases, a generic methodology is provided instead. This generic methodology is seen as robust enough to account for future development until development within the use case is mature enough for a case-specific methodology to be developed. One aspect of RAS deployment that this report does not address is emissions involved in the operation and usage of the RAS system, as it is outside the scope of this report. Instead, OLTER believes calculating the carbon intensity of individual RAS is the duty of RAS developers, not operators; NZTC already provides tools to partnered developers to perform accurate emissions calculations themselves. Operators may then compare the estimated annual abatement from the system with its emission deployment cost to determine the net carbon benefit received. Finally, a key aspect of this report is a focus on UKCS and the North Sea specifically. This is due to OLTER's contacts and the interviewed parties for this report having expertise primarily relevant to the North Sea. In some cases, the methodologies demonstrated may be applicable to other operating environments, but OLTER makes no guarantee. As such, it is not recommended to apply these methodologies to assets outside the UKCS unless prior consideration has been given to the relevancy of some of the assumptions made within this report.

Inter-Domain RAS Use Cases

1 Introduction

Inter-domain RAS use cases are those which persist across more than one of the land, sea, and air RAS domains. For example, optimizing POB can be achieved both through land-based robots monitoring equipment on an offshore rig, but also through the use of flying drones to do monitoring and maintenance. The methodologies for these use cases have therefore been selected to be accommodating of all domains to which the abatement use case might apply.

2 Optimized POB (Core Team)

Many of the current RAS have the potential to change offshore practices. For example, traditional survey by rope requires at least three individuals to be present to perform survey at height; if surveying is done over the side of a rig, this requirement rises to four. If a flying drone could be used to survey instead, the personnel requirements for surveying can be cut by two or three people; if a BVLOS operator is instead performing the inspection from shore, inspection POB can even be reduced to zero. Having robots navigate assets to monitor equipment and use computer vision to perform predictive maintenance reduces personnel requirements even further. Estimating the reduced carbon impact of using RAS for tasks is a complex issue. Each reduction in POB leads to reductions in the food required to be shipped offshore, the amount of potable water needed by the installation, and other reductions across the asset. At the same time, there is a recognition that RAS may only account for part of a persons' tasks while offshore. This report attempts to cover these factors as comprehensively as possible.

2.1 Key omissions

For the purposes of maintaining the accuracy of the final carbon abatement estimation, three categories have been deemed too complex or irrelevant to include within the abatement calculations: electricity and heating, apparel and hygiene products, and transportation to asset via boat. Operators may choose to account for these categories separately if they choose. As calculated carbon abatement would be higher yet less accurate if these categories were included in the primary abatement calculations, their omissions are in-line with this report's goal of keeping estimates conservative: a lower estimate with less variability is preferred to a higher estimate which is more variable.

2.1.1 Heating and Electricity

Electricity and heating considerations were removed from the calculation due to significant variation across rigs, and the likelihood that even a maximal reduction in POB due to RAS use might not be sufficient to provide abatement in these categories. This is due to electricity and heating being provided by gas turbines on the majority of assets. These turbines cannot just be "dialed down" if electricity load is minimally reduced, as would occur if a couple of cabins remained unused. There is perhaps potential for a reduction in emissions during crew changeover, as some assets might require an extra turbine to become online to support operations while a new crew is being onboarded and the old crew is preparing to depart. However, these changeover times vary across the year and by asset, and determining the personnel reduction required to omit the need for an extra turbine is also variable by asset; simply put, a reduction in gas turbine usage during changeover would most likely need to be measured after the introduction of RAS, and is quite difficult to predict beforehand.

In terms of potential turbine usage reduction in non-changeover times, even in the maximal case of a 39% reduction in offshore personnel as estimated by London Economics, this still may not be enough to reduce turbine usage on most rigs, as the majority of the electricity is required to maintain operations as opposed to providing heating and electricity to the crew. As such, electricity and heating carbon abatement from personnel reduction have been omitted from this report.

2.1.2 Apparel and goods transportation

Emissions from the transportation of apparel (spare uniforms), hygiene products, and other non-food and water items to assets have also been omitted from this report. Personal items are always brought by a worker on their flight in, and spare uniforms are kept on the rig and would need to be replaced infrequently. Workers occasionally purchase products from asset commissaries if they are available, but transactional volume is low. Due to the efficiency of platform supply vessels, the increase in abatement from reduced commissary usage would likely be less than 50kg CO2e annually, even with a large reduction in POB. As such, all non-food and water goods transportation for workers has been omitted for this report.

2.1.3 Transportation offshore – Vessel

Finally, transportation to offshore assets via boat has also been excluded from this report. This is due to transportation offshore by boat being essentially unheard of within the North Sea, practically all transport offshore is by helicopter. As such, when local operators were interviewed for data for this report, even personnel at major operators could not provide much information regarding personnel transfer by boat due to having mostly local expertise. For this reason, personnel transfer by boat has been omitted from the report due to a lack of information. OLTER may perform interviews and provide information on ship-based personnel transfer emissions in a future report.

2.2 Transportation offshore

All personnel transfer in this report is assumed to be performed either solely by helicopter, or by a mixture of local fixed-wing flight to a heliport and helicopter travel to an asset. For the purposes of classifying the abatement of reduced helicopter usage, three abatement calculation methodologies have been considered. Each abatement methodology has a different level of accuracy and is suitable for a different level of POB reduction.

2.2.1 Plane transportation

Before considering helicopter emissions, which are more difficult to quantify, one may first consider if personnel need to be flown to a heliport before taking a helicopter to an asset. In this case, emissions are calculated using the average passenger emissions conversion factor for domestic flights provided by the UK government [2]. The annual abatement is then the emissions per round trip multiplied by the number of trips per year. Assuming 3-week shifts and that the reduced role would have required personnel onboard year-round, this would be around 17 trips abated per year. Once the helicopter emissions reduction from each reduced POB is calculated, these plane emissions are added on top of the helicopter emissions to calculate the total transport emissions for transport offshore. Below is a table containing the recommended conversion factor and emissions reductions per person for abated flights from a variety of common O&G hubs to the Shetlands.

Table 1: Conversion factors for passenger flights to Shetlands and example scenarios

Conversion factor (kg CO2e/km for 1 passenger)	**City**	**Distance to Shetlands (km)**	**Abatement (kg CO2e) – Two-way, 1 passenger, 1 trip**	**Annual abatement (kg CO2e) – Two-way, 1 passenger, 17 trips**
0.27258	Aberdeen	≈ 340	185	3150
Conversion factor (CO2e/mi for 1 passenger)	Bristol	≈ 970	529	8990
0.43867	Glasgow	≈ 510	278	4730
	London	≈ 960	523	8900
Distances shown in this table are all straight-line distances, abatement may be larger depending on plane routing. Conversion factors retrieved from UK government's 2023 greenhouse gas conversion factors report **[2]**.				

Equation 1: Annual abatement from flights for a POB reduction n (km)

$$Abatement_{annual}(n) = n(Shetlands\_dist\_km_{2-way} * 0.27258 * num\_flights_{annual})$$

Equation 2: Annual abatement from flights for a POB reduction n (mi)

$$Abatement_{annual}(n) = n(Shetlands\_dist\_mi_{2-way} * 0.43867 * num\_flights_{annual})$$

2.2.2 Helicopter abatement – Free seats method

The least accurate method for calculating abatement of transportation-related emissions is the "free seats" method. This method is quite inaccurate, but may be found useful in cases where it is not expected that POB reductions will not lead to usage of smaller helicopters, or consolidation of flights. Instead, it is assumed that POB reductions will be used to prevent extra flights above baseline from being sent out. In these cases, the annual abatement is equivalent to the abatement of abating one helicopter flight to the asset of a helicopter class with the capacity equivalent to the seats "freed" by the

POB reduction, rounded down. For example, if POB of core team is reduced by 1, then 1 seat has been made available on 17 flights throughout the year (assuming the common North Sea shift length of 3 weeks). If a helicopter would have been chartered to fly a similar number of visitors to the asset at once within the same year, it can be assumed that those visitors may be split up to take the free seats offered over the year instead of visiting simultaneously. In the case of 17 free seats, an H175 with 16 seats could have instead been used to ferry most of the visitors, so the associated round-trip emissions of the H175 visiting the asset can be abated. This is an inelegant solution, and its inherent inaccuracy increases as it is used to calculate the abatement for higher POB reductions. However, without a logistical model, it provides a number which is slightly more representative than the naïve annual free seats divided by helicopter capacity approach, as long as the POB reduction remains low. The tables below demonstrate fuel usage and emissions profiles per nautical mile and kilometer of a variety of helicopters used to transport personnel offshore within the North Sea; associated calculations for "free seats" abatement for a variety of asset distances are also included.

Table 2: Fuel consumption at cruise, capacity, emissions at cruise, and emissions from landing and takeoff by helicopter type

Helicopter type	Capacity (seats)	Cruise fuel consumption (kg/h)*	Landing and takeoff emissions (kg CO2e)*	Cruise emissions (kg CO2e/nm)	Cruise emissions (kg CO2e/km)
S92-A	19	735.1	314	15.5	8.37
AW189	19	673.2**	288**	13.5	7.29
H175	16	455.2***	193***	9.65	5.21
AW139	15	412.2	175	7.94	4.29
Helicopter fuel consumption and LTO figures taken from FOCA study* **[3]. *UK government conversion factor used to convert between fuel usage and CO2 emissions* **[2]**. *The LTO emissions figure is the combined emissions from landing and takeoff.*					
***AW189 engine figures not included in FOCA report, but S92-A and AW189 share the same engine family. Table AW189 figures are linearly scaled from the S92-A figures based upon percentage difference (<10%) in engine* **[4]**.					
****H175 engine figures not included in FOCA report, but AW139 and H175 share the same engine family. Table H175 figures are linearly scaled from AW139 figures as above* **[5]**.					

Table 3: Free seats abatement scenarios for varied asset distances (helicopter only)

POB scenario	"Free seats" usage	Annual abatement (kg CO2e)		
		Asset @ 50 nm (≈ 90 km)*	**Asset @ 100 nm (≈ 190 km)***	**Asset @ 200 nm (≈ 370 km)***
1 reduction	17 seats, abates emissions from 16-capacity H175	1351	2316	4246
2 reductions	34 seats, abates emissions from 2x16-capacity H175	2702	4632	8492

2 reductions	34 seats, abates emissions from 1x19-capacity AW189 + 1x15-capacity AW139	3070	5214	9502

**In all cases where asset distances are used within this report, calculations are performed with twice the asset distance seen in the table to account for round-trip travel. LTO figures are also multiplied by two in calculations to account for two landings and takeoffs in a round-trip journey.*

2.2.3 Helicopter abatement – Helicopter class reduction

The next methodology to be discussed is reducing the class of helicopter used to transport individuals offshore. In this methodology, emissions are calculated by assuming that a helicopter with a lower personnel or weight capacity is used when a POB reduction occurs. For example, the S92-A is very commonly used offshore as it has the highest personnel capacity and can handle the highest amount of weight when flying offshore. However, the AW189 has the same personnel capacity (number of seats), but cannot handle as much weight as the S92-A; unsurprisingly, the AW189 has a lower emissions profile, as can be seen above. Therefore, if a RAS system leads to a POB reduction of 1, carbon abatement could be calculated by assuming that an AW189 is used to transport personnel offshore in lieu of an S92-A due to the reduced weight of personnel onboard. The annual carbon abatement would then be the carbon savings from each flight multiplied across the 17 reduced-class flights throughout the year (again assuming the North Sea average 3-week rotation). With larger POB reductions, operators could use helicopters with even fewer seats and emissions, such as the H175 or the AW139, reducing emissions per flight even further. If POB reduction is large enough, entire helicopter flights could even be abated. This methodology is the one used by OLTER's carbon abatement calculator, as it is the most accurate methodology discussed in this report that does not require logistical modelling. In order to allow for ease of use, the calculator requires the user to input normal helicopter type used for flights. The calculator will then assume these flights are evenly distributed among the year, and will attempt to declass helicopter flights evenly as well. This may not be perfectly accurate to an operator's flight patterns, but it is seen as a way to maximize ease of usability of the tool whilst retaining a reasonable amount of accuracy. Below is a table of emission reductions one might see for certain POB reduction and declassing scenarios.

Table 4: Annual abatement from helicopter declassing scenarios

POB Scenario	**Declassing Opportunity**	**Annual abatement (kg CO2e)**		
		Asset @ 50 nm (≈ 90 km)	**Asset @ 100 nm (≈ 190 km)**	**Asset @ 200 nm (≈ 370 km)**
1 reduction	Use AW189 in lieu of S92-A, 17 flights per year	4284	7684	14484
3 reductions	Use H175 in leu of S92-A, 17 flights per year	14059	24004	43884
3 reductions	Use AW189 in leu of S92-A, 51 flights per year	12852	23052	43452

5 reductions	Use AW189 in lieu of S92-A, 17 flights per year; Use H175 in leu of S92-A, 17 flights per year	18343	31688	58378
5 reductions	Use AW189 in lieu of S92-A, 17 flights per year; Use AW139 in lieu of S92-A, 17 flights per year	21861	38114	70618
All abatement calculations performed using LTO and cruise emissions figures from table 2				

Table 5: Abatement from reduction in helicopter flights

Helicopter type	**Emissions per flight (kg CO2e)**		
	Asset @ 50 nm (≈ 90 km)	**Asset @ 100 nm (≈ 190 km)**	**Asset @ 200 nm (≈ 370 km)**
S92-A	2178	3728	6828
AW189	1926	3276	5976
H175	1351	2316	4246
AW139	1144	1932	3500
All emissions calculations performed using LTO and cruise emissions figures from table 2			

Equation 3: Annual abatement from individual helicopter declassing

$$Abatement_{annual} = num\_flights_{annual}(distance_{asset(2-way)} * \left(emissions_{cruise(old-heli)} - emissions_{cruise(new-heli)}\right) + 2 * (emissions_{LTO(old-heli)} - emissions_{LTO(new-heli)}))$$

Equation 4: Annual abatement from individual helicopter usage reductions

$$Abatement_{annual} = flights\_reduced_{annual}(distance_{asset(2-way)} * emissions_{cruise} + 2 * emissions_{LTO})$$

2.2.4 Helicopter abatement – Logistical modelling

Finally, the last methodology for calculating reductions in helicopter emissions is to perform logistical modelling. This would be too difficult to implement for OLTER’s calculator due to a lack of information regarding individual operator flight paths and operations, but all major operators already perform modelling to optimize logistical scenarios. In the case of POB reduction, this allows operators to model the resulting carbon abatement most accurately. For example, if there is a cluster of assets, POB reduction on each asset could allow for flights to be consolidated, perhaps leading to the abatement of an entire flight; declassing can also be modelled more accurately, accounting for the fact that many times helicopters must fly offshore at reduced capacity due to poor weather. Again, the associated emissions for declassing and abating flights can be seen in the tables above, and can be used to directly calculate emissions outcomes from modelled scenarios.

2.3 Food

The quality and quantity of food available on offshore rigs is an essential component in maintaining the morale of offshore personnel. Additionally, offshore work is strenuous and often stressful, leading to larger calorific intake due to exertion and occasional stress eating. Offshore workers will eat an average of over 3000 calories per day, although for the purposes of these calculations a value of 3000 will be used [6]. It is assumed that 1 calorie is equivalent to roughly 1g of food, so that workers require around 3kg of food per day when working offshore. While individual workers work rotations, a reduction in POB will lead to reduced food demand year-round; hence, 3kg of daily food consumption spread over the year is equivalent to almost 1.1 tonnes (1095kg) of food deliveries to the asset per year. To keep calculations conservative, it is assumed that there is zero food waste on the installation. The abatement for a reduction of 1 in POB would then be equivalent to the equivalent emissions for a ship of a given class to transport 1.1 tonnes of food to the asset and to return, accounting for standby and dynamic positioning (DP) time. To keep estimate calculations conservative, the associated emissions per tonne of cargo transported are calculated assuming vessels deliver food at ECO speed and fuel consumption, and with the vessel's entire deadweight tonnage utilized. Additionally, average DP and standby times are assumed per delivery for each vessel class. The averages for cargo emissions calculations can be seen below, and are based upon averages provided to OLTER by a major offshore energy provider. OLTER's calculator will use these averages by default for calculations.

Table 6: Emissions conversion factors for various ship classes at ECO-speed

Emissions categories	Vessel deadweight tonnage			
	1000-2000t	2000-3000t**	3000-4000t**	4000-5000t
Average daily fuel usage (t MGO/day)	1.473	3.155	4.615	6.300
Average daily emissions (t CO2e/day)*	4.780	10.24	18.22	20.45
Average ECO shipping emissions (kg CO2e/nm/t deadweight)***	0.02643	0.03259	0.03600	0.03851
*MGO usage converted to daily emissions using UK government 2023 GHG conversion factors [2].				
**The vessel data OLTER received did not include any ships in the 2000-4000t deadweight ranges. This is due to there being a general trend in PSV development to create larger and slower ships [7]. Therefore, the conversion factors for the 2000-3000t and 3000-4000t categories have been interpolated using a fuel curve. More information on the fuel curve used can be found in Section 4: Vessel Improvement of the Sea Domain Use Cases on page 24.				
***These conversion factors include standby and DP time for visiting an asset. These values were calculated accounting for a vessel activity breakdown of 21% DP time, 43% standby time and 36% transit time while delivering cargo; this is a fleet				

average, larger and smaller vessels will have a larger and smaller share of DP and standby time respectively due to changes in offloading and onloading times at assets.

Equation 5: Annual abatement from food consumption for a POB reduction n

$$Abatement_{annual}(n) = n(1.095 * conversion\_factor \ * distance_{asset(2-way)})$$

2.4 Water

The water demand for an offshore installation is dependent on the desalination facilities available to the facility. If desalination already exists within a given facility, no abatement will be received by the operator. However, if an operator needs to ship potable water out to an asset, then each reduction in POB comes with a significant associated potable water demand reduction. For the average person between the ages of 20-50 years of age, daily drinking water consumption in millilitres is roughly 1.37 times a person's daily calorie intake [8]. For our assumption of 3000 calories per POB per day, this equates to around 4.1litres (4110ml) of drinking water per POB per day, or 4.11kg of water per POB per day (1.5 tonnes a year). However, water usage per person goes beyond simply drinking water: considerations must also be made for reductions in potable water required for showering and laundry per person as well. For showering, it is assumed that workers shower for the average UK shower time of 7.5 minutes and that reduced flow shower heads are used with a flow of 10 litres per minute, leading to a water usage of 75 litres or kg per daily shower. Meanwhile, it is also assumed that offshore workers need about one load of laundry done per week as is also the UK average, with the average water usage per load being 53kg [9]. It is assumed dishwashing is done with salt water and is hence not included in this calculation. This leads to the average offshore worker requiring 86.7 kg of water per day; over the year, this is 31.6 tonnes of water needed per worker on an installation. This number can be correlated with table 6 above to determine the abatement gained per POB reduction for a given asset distance.

Equation 6: Annual abatement from water consumption for a POB reduction n (no desalination)

$$Abatement_{annual}(n) = n(31.6 * conversion\_factor * distance_{asset(2-way)})$$

2.5 Custodial staff reduction

Custodial staff are required on offshore installations to cook food for and clean the cabins of workers. The exact number of staff required per crew members on board an installation is contractually regulated, but general numbers might be 10 crew members to 1 custodial staff up to 100 POB, and then 15 crew members to 1 custodial staff for additional POB over 100. OLTER's calculator uses these averages. The implication of these ratios is that additional POB can be gained if certain POB reductions from baseline are achieved. For example, if an installation with baseline POB of 85 has a POB reduction due to RAS of 6, this reduction becomes 7 due to 1 fewer custodial staff being required on board as well.

2.6 Combined emissions profile per POB reduction

Below the individual equations from each category are combined into the full equation for abatement per POB reduction. The below table also provides some abatement calculations for certain scenarios.

Table 7: Annual abatement for POB reductions scenarios

POB reduction	**Scenario**	**Annual abatement (t CO2e)**		
		Asset @ 50 nm (≈ 90 km)	**Asset @ 100 nm (≈ 190 km)**	**Asset @ 200 nm (≈ 370 km)**
1 reduction	Free seats abatement, 1 H175 flight abated; flights from Aberdeen to Shetlands	4.501	5.466	7.396
1 reduction	AW189 used in lieu of S92-A, 17 flights per year; no desalination on asset	4.410	7.936	14.99
3 reductions	H175 used in leu of S92-A, 17 flights per year; no desalination on asset	14.44	24.76	45.41
5 reductions	AW189 used in lieu of S92-A, 17 flights per year; AW139 used in lieu of S92-A, 17 flights per year; Flights from~ Aberdeen to Shetlands	37.18	54.76	86.39
19 reductions	17 S92-A flights abated per year	36.36	64.91	116.3
19 reductions	17 S92-A flights abated per year; no desalination on asset; flights from Aberdeen to Shetlands	98.48	129.5	185.4
All calculations in this table assume that a PSV of 4000-5000t deadweight is being used for transport, as these larger vessels are most commonly used in the North Sea.				

Equation 7: Combined annual abatement for a POB reduction n

$$Abatement_{annual}(n) = emissions_{transport}(n) + emissions_{food}(n) + emissions_{water}(n)$$

3 Optimized POB (Emergency Maintenance)

While RAS have the potential to reduce the POB required to maintain an offshore installation, another potential usage is on normally unmanned facilities (NUFs or NUIs). While these facilities are technically “unmanned,” they receive frequent visits by maintenance crews, some as frequently as once a month or more. However, in many cases, on-site inspection by maintenance personnel finds that alarms were triggered erroneously, and that significant maintenance is not required. As such, a majority of these visits are frivolous, and some operators expect that by deploying RAS to inspect issues before sending out a maintenance team, annual necessary visits could be reduced significantly. In these cases, carbon abatement is significantly easier to calculate than in the core team POB scenario, as RAS deployment directly leads to a reduction in annual helicopter visits. For this case, the abatement for each NUF which receives the RAS system is equal to the expected reduction in helicopter visits annually multiplied by the round-trip emissions for the helicopter type used for transport of the maintenance crew. Helicopter abatement conversion factors from Section 2.2 have been repeated below, and some NUF RAS deployment scenarios are considered. In cases where maintenance crews are normally retrieved from one asset before being flown to the NUF, LTO emissions may need to be accounted for more than twice. For example, if an average trip to a NUF requires two stops (once at an asset to pick up crew, and once at the NUF) then 3 landings and takeoffs must be accounted for; OLTER’s calculator is robust to these inputs.

Table 8: NUF RAS deployment abatement scenarios and corresponding flight abatement

Helicopter type	**LTO emissions (kg CO2e)***	**Cruise emissions (kg CO2e/nm)***	**NUF abatement – 8 reduced flights per year, round trip 100 nm/190 km (t CO2e/year)**	**NUF abatement – 6 reduced flights per year, round trip 200 nm/370 km (t CO2e/year)**
S92-A	314	15.5	17.42	22.37
AW189	288	13.5	15.41	19.66
H175	193	9.65	10.81	13.90
AW139	175	7.94	9.152	11.63
*Figures retrieved from table 2 in Section 2.2				

Equation 8: Annual abatement for reduction in emergency trips to an asset

$$Abatement_{annual} = trips\_reduced_{annual} * (emissions_{cruise} * distance_{asset(2-way)} + 2 * emissions_{LTO})$$

4 Logistics (Cargo transport and emergency deliveries)

To alleviate confusion, logistics use cases are broken up into sea and air categories due to deliveries being made by both platform supply vessels and helicopters. For this section, sea logistics refers to reducing the emissions of cargo transport by a sea-based vessel by instead using a sea or air domain RAS system. Similarly, air logistics refers to reducing the emissions of cargo transport by helicopters by again using a RAS system within either domain. To be clear, the sea section does not refer purely to sea domain RAS, and the air section does not refer purely to air domain RAS. This decision was made to reduce repetition within both sections, and is reflected in the design of the OLTER carbon abatement calculator.

4.1 Sea

Platform supply vessels (PSVs) are the most common method of transporting cargo to offshore facilities. These vessels are very efficient in terms of fuel usage per tonne transported offshore, but are very carbon intense, especially when accounting for loiter time outside rigs due to poor weather and fuel usage at full speed for critical deliveries. As stated above, RAS can be utilized to reduce fuel usage and frequency of use of supply vessels: currently, lighter items (<40 kg) can be transported to platforms using battery-powered flying drones within certain ranges, while heavier items can be transported on smaller autonomous seafaring vessels. Many developers are also working to design air domain RAS systems to transport heavier goods offshore as well. Deliveries can be categorized into normally scheduled deliveries, and unscheduled emergency deliveries; the methodologies for the two categories of delivery are distinct.

For scheduled deliveries, emissions reduction can be based on either a reduction in trips a vessel would need to take to a platform within a year, or by a reduction in the deadweight tonnage a supply vessel would need to supply the platform within the year; there is also a scenario wherein a reduced tonnage vessel would make fewer trips than normal within a year due to RAS impacts. For the trips reduction scenario, abatement is calculated by finding the time in DP, standby, and steaming for an average delivery to the asset, and then multiplying these times by the average asset visits per year, fuel usage for each transit mode, and the conversion factor for MGO to CO2e. Fuel usage can also be calculated by using a daily fuel usage figure and breaking this usage down into transit, DP and standby categories. This method, combined with a fleet consumption mode breakdown of 21% DP time, 43% standby time, and 36% ECO transit time is assumed in the OLTER calculator. When reducing the deadweight tonnage of a vessel instead, the above calculation must be performed for both vessel classes using the total trips needed for the asset per year, with the difference being the resulting carbon abatement. Finally, if RAS deployment leads to both reduced trips and a reduction in vessel tonnage requirement, total abatement is equal to the full abatement gained from the reduction in trips by the higher tonnage vessel, added to the difference in emissions between the two vessels for the remaining trips.

Table 9: Emissions conversion factors for various ship classes at ECO-speed

Emissions categories	**Vessel deadweight tonnage**			
	1000-2000t	**2000-3000t****	**3000-4000t****	**4000-5000t**
Average daily fuel usage (t MGO/day)	1.473	3.155	4.615	6.300

Average daily emissions (t CO2e/day)*	4.780	10.24	18.22	20.45
Average ECO shipping emissions (kg CO2e/nm/t deadweight)***	0.02643	0.03259	0.03600	0.03851
*MGO usage converted to daily emissions using UK government 2023 GHG conversion factors **[2]**.				
******The vessel data OLTER received did not include any ships in the 2000-4000t deadweight ranges. This is due to there being a general trend in PSV development to create larger and slower ships **[7]**. Therefore, the conversion factors for the 2000-3000t and 3000-4000t categories have been interpolated using a fuel curve. More information on the fuel curve used can be found in Section 4: Vessel Improvement of the Sea Domain Use Cases on page 24.				
*******These conversion factors include standby and DP time for visiting an asset. These values were calculated accounting for a vessel activity breakdown of 21% DP time, 43% standby time and 36% transit time while delivering cargo; this is a fleet average, larger and smaller vessels will have a larger and smaller share of DP and standby time respectively due to changes in offloading and onloading times at assets.				

Equation 9: Annual abatement from reducing supply vessel trips to asset

$$Abatement_{annual} = reduced\_trips_{annual} * conversion\_factor * distance_{asset,2-way}$$

Equation 10: Annual abatement from reducing tonnage of supply vessel for an asset

$$\begin{aligned} Abatement_{annual} &\\ &= trips_{annual} * (conversion\_factor_{old-vessel} - conversion\_factor_{new-vessel}) \\ &* distance_{asset(2-way)} \end{aligned}$$

Equation 11: Annual abatement from reducing supply vessel trips and tonnage of supply vessel for an asset

$$\begin{aligned} Abatement_{annual} &\\ &= reduced\_trips_{annual} * conversion_{factor_{old}} * distance_{asset,2-way} \\ &+ declassed\_trips_{annual} * (conversion\_factor_{old-vessel} - conversion\_factor_{new-vessel}) \\ &* distance_{asset(2-way)} \end{aligned}$$

In terms of reductions in emergency deliveries, abatement is based upon the expected number of reduced emergency deliveries per year by vessels (as these deliveries will instead be performed by RAS system), and the distance of the asset in question. In this case, the entirety of the vessel's emissions for the trip are counted as abatement, regardless of the tonnage of the item being delivered and if other non-emergency items are loaded onto the vessel. This is because any additional items which may have been loaded alongside the critical delivery would have been shipped to the rig during a normally scheduled delivery. No abatement is gained from reducing the tonnage of the normal delivery in this case as at full speed (it is assumed that a vessel will always travel at full speed during a critical delivery), fuel usage is almost double what is consumed at ECO speed. Therefore, additional cargo added on critical delivery voyages is neglected in the calculations; this is in line with the report's goal of remaining conservative in abatement estimates. Emissions figures for common vessel classes at full speed can be seen in table 10 below. Some abatement scenarios which may be achieved through elimination of unscheduled emergency cargo delivery by PSV can also be found.

Table 10: Emissions for critical delivery by various ship classes at full speed

Emissions categories	**Vessel deadweight tonnage**			
	1000-2000t	**2000-3000t**	**3000-4000t**	**4000-5000t**
Average critical delivery emissions (kg CO2e/nm)	40.3	88.4	134	188
Delivery emissions – Round-trip 100 nm/190 km (kg CO2e)	4030	8840	13400	18800
Delivery emissions – Round-trip 200 nm/370 km (kg CO2e)	8060	17680	26800	37600
Delivery emissions – Round-trip 400 nm/740 km (kg CO2e)	16120	35360	53600	75200
Figures calculated in the same way as in table 6 in Section 2.3; the same caveats apply for vessels between 2000-4000t deadweight.				

Equation 12: Annual abatement from reduced supply vessel emergency deliveries for a given asset

$$Abatement_{annual} = reduced\_trips_{annual} * conversion\_factor * distance_{asset(\,2-way)}$$

One issue operators may face is determining the number of emergency deliveries an asset may require and which may be reduced within a given year. In this case, numbers from previous years or a yearly average over multiple previous years may provide a good estimate of the number of deliveries reduced annually for the asset. Additionally, it may be the case that a RAS system can only handle a certain weight of equipment, and any equipment above that weight will have to be sent out by PSV. In this case, the expected value for abatement will be the full abatement multiplied by the probability that a piece of equipment that has broken is able to be shipped out using a RAS system; this probability can be extrapolated using previous years' data as well.

4.2 Air

Helicopters are less often used to send equipment out to offshore facilities but will often be used for time-critical deliveries. Just as with supply vessel deliveries, helicopter deliveries can be split into normal delivery and emergency delivery categories. Abatement of emergency deliveries, in particular, can lead to significant carbon abatement; interviewing with an OIM from a major offshore energy producer revealed that in an emergency delivery an entire helicopter could be flown out solely for the delivery of a critical washer or O-ring. OLTER market research has demonstrated that the use of drones with a maximum of 40kg of capacity could replace up to 90% of unscheduled parts delivery by helicopter. Just as with critical deliveries by sea, the entirety of the emissions of the emergency helicopter trip are counted for abatement in this scenario. Abatement is simply calculated by multiplying the round-trip distance for a helicopter to visit the asset by the fuel usage for the class of helicopter and then by the average emergency trips to the asset per year. As above, the number of emergency trips per asset can be estimated using data from previous years. Reference figures for common helicopters used offshore can be seen in table 11 below; calculations for these figures are identical to those used in the optimized POB scenarios.

Table 11: Abatement from reduction in helicopter flights for emergency use

Helicopter type	**Emissions per flight (kg CO2e)**		
	Asset @ 50 nm (≈ 90 km)	**Asset @ 100 nm (≈ 190 km)**	**Asset @ 200 nm (≈ 370 km)**
S92-A	2178	3728	6828
AW189	1926	3276	5976
H175	1351	2316	4246
AW139	1144	1932	3500
All emissions calculations performed using LTO and cruise emissions figures from table 2 in Section 2.2			

Table 12: Abatement conversion factors for helicopter flights for emergency use

Helicopter type	**LTO emissions (kg CO2e)**	**Cruise emissions (kg CO2e/nm)**	**Cruise emissions (kg CO2e/km)**
S92-A	314	15.5	8.37
AW189	288	13.5	7.29
H175	193	9.65	5.21
AW139	175	7.94	4.29

Equation 13: Annual abatement from reduced helicopter emergency deliveries to asset

$$Abatement_{annual} = reduced\_trips_{annual}(emissions_{cruise} * distance_{asset(2-way)} + 2 * emissions_{LTO})$$

Meanwhile, for scheduled cargo deliveries by helicopter, emissions reduction is based upon the number of reduced cargo deliveries expected within a year multiplied by round trip distance and fuel usage of the helicopter type. This provides a calculation for carbon abatement assuming that RAS deployment would offset enough air cargo from helicopters that a number of trips would be reduced. Another possible outcome of RAS deployment could be that scheduled deliveries are performed with a lighter helicopter class than usual, which would also reduce emissions. This could be calculated by comparing the emissions produced by the normal round-trip distances and annual trips per year for the asset across the heavier and lighter helicopter. Again, reference figures for the fuel usage of these different helicopters can be seen above in table 12.

Equation 14: Annual abatement from reduced normal helicopter deliveries

$$Abatement_{annual} = reduced\_trips_{annual}(emissions_{cruise} * distance_{asset(2-way)} + 2 * emissions_{LTO})$$

Equation 15: Annual abatement from declassing of helicopters for scheduled deliveries

$$\begin{aligned} Abatement_{annual} & \\ &= declassed\_trips_{annual}[(emissions_{cruise(old-heli)} - emissions_{cruise(new-heli)}) \\ &* distance_{asset(2-way)} + 2 * (emissions_{LTO(old-heli)} - emissions_{LTO(new-heli)})] \end{aligned}$$

Equation 16: Annual abatement from declassing of helicopters and reduced cargo flights for normal deliveries

$$\begin{aligned} Abatement_{annual} & \\ &= reduced\_trips_{annual}(emissions_{cruise(old-heli)} * distance_{asset(2-way)} + 2 \\ &* emissions_{LTO(old-heli)}) \\ &+ declassed\_trips_{annual}[(emissions_{cruise(old-heli)} - emissions_{cruise(new-heli)}) \\ &* distance_{asset(2-way)} + 2 * (emissions_{LTO(old-heli)} - emissions_{LTO(new-heli)})] \end{aligned}$$

Sea Domain-Specific Use Cases

1 Introduction

To account for future RAS system development which cannot be accurately predicted and recognizing that the sea domain is seeing significant offering development, the sea domain use cases have been split into a few specific use cases and then a general “vessel improvement” category. The specific use case sections propose methodologies which are relevant to current technologies and are adapted to account for expected RAS offering developments within those fields. Meanwhile, the vessel improvement category provides a methodology to calculate abatement for a generic RAS technology which may improve vessel tonnage, reduce annual vessel utilization etc. Providing both specific and generic methodologies for the sea domain is in-line with this report’s goal of attempting to account for future developments as much as possible.

2 Subsea Equipment Survey

RAS system development regarding monitoring of subsea equipment is quite advanced. Systems are being developed to allow small, unmanned vessels to follow along the length of pipelines with monitoring equipment, providing full monitoring capability without the need for a much larger crewed vessel. These systems can also be applied to work near assets, transporting ROVs to subsea tiebacks to monitor christmas trees, blowout valves, and other equipment. Based on the specific equipment these systems are monitoring, and the types of vessels they are replacing, the carbon abatement potential of these systems may vary.

2.1 Pipeline Surveying

Systems looking to replace traditional pipeline surveying vessels can expect to provide significant amounts of carbon abatement. The current method for pipeline surveying is having a fully-crewed vessel follow along the length of a pipeline as ROVs are deployed to perform the survey. This means that the crewed vessel must “hover” over the ROV while it is deployed. This is done using DP, as pipeline survey is too slow for the vessel to traverse the pipeline at any speed. This leads to a different vessel emissions profile from traditional surveying or cargo transport, as fuel consumption averages at around 8.5t per day but at a speed of only 1.5-2.5 knots. By replacing a fully crewed surface vessel with an autonomous or remotely operated ROV deployment RAS system, significant abatement can be obtained. The abatement in this case would be the number of trips the RAS system is deployed on within a year multiplied by average fuel consumption emissions for the average class of vessel which would have performed the surveys instead, and the average pipeline survey path length. Additionally, the emissions from steaming to and from the survey site must also be accounted for. Different conversion factors must be used for ECO steaming emissions and survey emissions due to their varying emissions intensities; conversion factors for surveying can be seen in table 14 below, and ECO speed conversion factors may be seen in table 16. OLTER’s calculator assumes an average fuel usage of roughly 8.5t of fuel per day with a survey speed of roughly 2 knots for 4500t vessels. Abatement from some pipeline survey scenarios may also be seen in table 15.

Table 13: Pipeline survey abatement conversion factors and abatement scenarios

Emissions categories	**Vessel deadweight tonnage**			
	1000-2000t	**2000-3000t****	**3000-4000t****	**4000-5000t**
Average daily fuel usage (t MGO/day)	3.971	5.555	7.015	8.5
Average daily emissions (t CO2e/day)*	12.89	18.03	22.77	27.59
Average ECO speed emissions (kg CO2e/nm)	257.8	360.6	455.4	551.8
Average ECO speed emissions (kg CO2e/km)	139.2	194.7	245.9	297.9
*MGO usage converted to daily emissions using UK government 2023 GHG conversion factors **[2]**.				
**These columns interpolated using fuel curve seen on page 25.				

Table 14: Pipeline survey abatement scenarios (Per survey not per year)

Abatement Scenario	**Per survey abatement (t CO2e)**
Replacement of 1000km pipeline survey, 300km round-trip to and from pipeline; 4500t vessel	319.9
Replacement of 21 day pipeline survey campaign, 3 days round-trip to steam to and from pipeline; 2000t vessel	352.4
Replacement of 21 day pipeline survey campaign, 3 days round-trip to steam to and from pipeline; 4500t vessel	636.7

Equation 17: Annual abatement from RAS deployment for pipeline surveying (One vessel)

$$Abatement_{annual} = surveys_{annual}(length_{pipeline/survey} * conversion\_factor + distance_{pipeline(2-way)} * conversion\_factor)$$

2.2 Subsea Tiebacks Survey

Subsea tiebacks are traditionally surveyed by independent vessels which transport ROVs directly to sites before steaming back to shore or to another tieback site after inspection. RAS can fulfill this surveying role by increasing vessel efficiency, replacing crewed vessels with smaller autonomous vessels, or a combination of both methods. For replacement of vessels, the carbon abatement which can be attributed to the deployment of a RAS system is equivalent to the round-trip distance the vessel may take to survey one or more subsea tieback sites. This can be slightly complicated depending on the type of RAS system deployed. For example, if the RAS system replaces a vessel by travelling the same survey routes with a reduced carbon footprint, then it would be accurate to abate the full amount of emissions of a similar trip done by a crewed vessel. However, if a system can only do the inspection for the tiebacks of one asset (if the system travels to and from the tiebacks and the asset to handle inspection and resupply), a crewed vessel may still be used for inspection of other tiebacks from other assets which do not have the RAS system deployed. In this secondary case, the operator would only receive abatement for the full trip if all assets within a given survey route received the RAS system.

To account for both cases, abatement can be calculated by finding the route distance reduction caused by the RAS system, as well as by finding the reduction in tieback sites a vessel would visit within a specific trip. The emissions abatement from the distance reduction and the reduction in dynamic positioning time (average is 5 days per tieback site visited) can then be multiplied by the number of times the route is travelled a year for an annual abatement figure. Reference figures for calculating emissions reductions while surveying can be seen in table 14 above, while figures for steaming to a survey site can be found in table 16 below; OLTER’s carbon abatement tool assumes that a vessel is under dynamic position for an average of 5 days while surveying takes place, but an operator may specify another value if desired. It is understood that the routes survey ships take are generally dynamically generated, so that abating a hypothetical single “route” for a number of trips a year is not entirely representative of real-world operation. However, centering the calculation around route distance reduction and sites visited makes it robust to multiple inputs. An operator could achieve an accurate abatement figure through looking at past survey trip data and then using the average distance travelled by vessels to the RAS-monitored tieback sites multiplied by average visits to the tieback sites a year to calculate abatement; in the case of vessel replacement, an operator could look at one or more survey vessels they may want to replace and then use the distances travelled and sites visited by all depreciated vessels in the previous year as an input into the model. Overall, this methodology for abatement calculation is recommended as it not only robust to multiple inputs, but also accounts for both per-vessel and per-asset tieback survey RAS.

Table 15: Abatement scenarios for subsea tieback survey

Abatement Scenario	**Scenario abatement (t CO2e)**
Abatement of survey of 4 tiebacks surrounding 1 asset, asset is 150km from shore; 4500t vessel; 5 days to survey 1 tieback	572.9
Abatement of 1 vessel’s annual surveying burden: 60 days steaming, 15 tiebacks surveyed; 2000t vessel; 5 days to survey 1 tieback	1647
Abatement of 1 vessel’s annual surveying burden: 60 days steaming, 15 tiebacks	3246

surveyed; 4500t vessel; 5 days to survey 1 tieback	

Equation 18: Annual abatement from RAS deployment for subsea tieback survey (One vessel)

$$Abatement_{annual} = steam\_time_{annual} * conversion\_factor + survey\_time_{per-tieback} * tiebacks\_surveyed_{annual}$$

3 Subsea Seismic Survey

At present, there are no applicable RAS which provide directly attributable carbon abatement. NZTC has collaborated with companies in the past to develop RAS to perform autonomous seismic survey, however the TRL of these technologies is still too low to determine if they would reduce vessel usage significantly [10].Therefore, the abatement derived from subsea seismic surveys has been omitted from this report for the time being. As current technologies develop, it is expected that the generic vessel improvement category will be able to account for the abatement provided by these systems. However, OLTER may investigate and develop methodologies for subsea seismic RAS abatement in the future, once it is clearer how developers plan to develop systems for the seismic space.

4 Vessel Improvement

As stated in this section’s introduction, the vessel improvement methodology is a generic methodology, created to account for future RAS development. New RAS are accounted for by categorizing them into tonnage, emissions, or utilization domains; a RAS system is assumed to improve upon a vessel by reducing its tonnage, decreasing its emissions by a certain percentage, reducing the amount the vessel needs to be utilized, or some combination of the three.

In the tonnage domain, the reduced tonnage from baseline is used to estimate the decrease in fuel usage for the vessel assuming normal usage. An operator may choose to match the new required tonnage to a known vessel’s fuel consumption, but for OLTER’s calculator a regression match is used. This regression was performed upon vessel data shared by a major offshore energy provider, and the regression is linear; a quadratic regression would match the data better, but polynomial regressions are prone to overfitting. Additionally, a linear match makes sense physically due to kinetic energy calculations having a linear mass term rather than a quadratic mass term; a linear regression also matches previous correlations from studies with larger data sets [11]. The average time the vessel would normally spend annually on standby, on DP, and steaming are also required for an accurate estimate of abatement; OLTER’s calculator will assume a cargo transport-relevant breakdown of 36% for steaming, 43% for standby, and 21% for DP based on shared data. A graph of the fit and its associated equation may be seen below, only vessels between 1200 and 5400 deadweight tonnage were used so any new vessel tonnage below 1200 tonnes will have a less accurate estimate of new fuel consumption due to extrapolation. A table of carbon abatement for certain reduced vessel tonnage scenarios is also given.

Figure 1: Linear match to vessel daily fuel consumption vs. deadweight tonnage

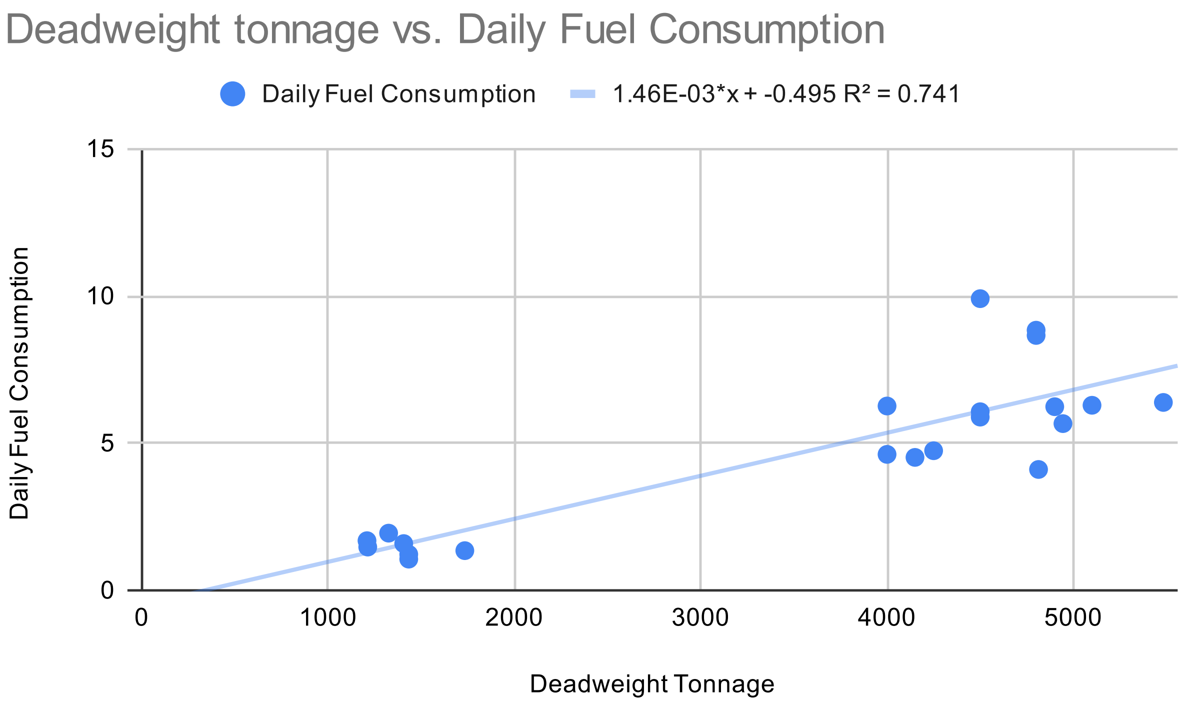

Table 16: Emissions conversion factors for utilization metrics for various ship classes at ECO-speed

Emissions categories	**Vessel deadweight tonnage**			
	1000-2000t	**2000-3000t****	**3000-4000t****	**4000-5000t**
Average daily fuel usage (t MGO/day)	1.473	3.155	4.615	6.300
Average daily emissions (t CO2e/day)*	4.780	10.24	18.22	20.45
Average ECO speed emissions (kg CO2e/nm)	11.35	25.10	38.83	54.87
Average ECO speed emissions (kg CO2e/km)	6.126	13.55	20.97	29.63

*MGO usage converted to daily emissions using UK government 2023 GHG conversion factors **[2]**.

**These columns interpolated using above fuel curve

Equation 19: Carbon abatement from vessel improvement in the tonnage domain (conversion factors)

$$Abatement_{annual} = (consumption_{old} - consumption_{new}) * conversion\_factor * travel\_distance_{annual}$$

For the emission reduction domain, carbon abatement is calculated by assuming a given percentage of vessel emissions are abated by a RAS deployment which improves efficiency. Again, the vessel's tonnage and average time spent annually in different consumption modes is required; in the calculator the vessel's fuel consumption is estimated via regression. The calculation then simply finds the normal emissions for the vessel and reduces these by the given percentage. The calculated reduction is the abatement.

Equation 20: Carbon abatement from vessel improvement in the emissions reduction domain (conversion factors)

$$Abatement_{annual} = \%reduction_{emissions} * conversion\_factor * travel\_distance_{annual}$$

In the utilization reduction domain, abatement is calculated assuming a RAS deployment increases the speed at which vessel activity is conducted, reducing the time or distance a vessel must be deployed for. This could be in cases where a surveying campaign is reduced in length due to increased efficiency due to RAS usage, or RAS deployment reduces the distance a vessel needs to travel to perform some activity. In these cases, all that is required is the estimated reduction in length of the activity performed, either in days, or distance. These can then be associated with the vessel tonnage or given vessel fuel consumption to determine the reduction in emissions due to the reduction in vessel usage. Table 16 above contains conversion factors for each covered utilization metric. Table 17 below demonstrates calculations for sample abatement scenarios where vessel utilization is reduced.

Table 17: Vessel utilization abatement scenarios

Utilization reduction per trip	**Vessel deadweight tonnage**			
	1000-2000t	**2000-3000t**	**3000-4000t**	**4000-5000t**
3 days **(7 days)** **- t CO2e/trip**	14.34 (33.46)	30.72 (71.68)	54.66 (127.5)	61.35 (143.1)
300 km **(1000 km)** **- t CO2e/trip**	1.837 (6.126)	4.065 (13.55)	6.291 (20.97)	8.889 (29.63)
100 nm **(400 nm)** **- t CO2e/trip**	1.135 (4.540)	2.510 (10.04)	3.883 (15.53)	5.487 (21.95)

Equation 21: Carbon abatement from vessel improvement in utilization reduction domain

$$Abatement_{annual} = reduction_{utilization} * conversion\_factor$$

Finally, in the case where multiple types of vessel improvements are accounted for at the same time, the abatement of each domain must be accounted for in order to ensure that the abatement calculation is accurate. In all cases, if there is a utilization reduction, it must be accounted for first. This reduction is accounted for at the baseline tonnage of the vessel and with no emissions reduction, even if a tonnage reduction or emissions reduction is also involved in the calculation. Secondly, the abatement from tonnage reduction is accounted for if applicable. This calculation obviously omits days or distances which have already been abated. Lastly, the abatement from the emissions percentage reduction is accounted for. This reduction is based upon the new fuel usage of the reduced tonnage vessel if applicable, to avoid double counting. Again, days or distances which have already been abated are omitted.

Equation 22: Carbon abatement from vessel improvement in all domains

$$\begin{aligned} Abatement_{annual} &\\ = reduction_{utilization} * conversion\_factor_{old-vessel} + utilization_{new} &\\ * (conversion\_factor_{old-vessel} - conversion\_factor_{new-vessel}) &\\ + \%reduction_{emissions}(utilization_{new} * conversion\_factor_{new-vessel}) & \end{aligned}$$

Air Domain-Specific Use Cases

1 Aerial Methane Monitoring

The usage of autonomous drones to perform fugitive methane emissions monitoring is becoming increasingly common in the UKCS. These drones, which may be either rotary or fixed-wing, will fly a holding pattern around an asset while taking measurements to determine methane emission intensity. At present, the most accurate sensors for rotary drones can detect emissions rates as low as 0.5kg/h [12], whereas the most accurate sensors for fixed-wind drones can detect rates above 2.5kg/h [13]. However, rotary drones must be flown within 50m of an asset, whereas fixed-wing drones may hold outside the 500m exclusion zone for reduced accuracy or request permission to fly at 250m for optimal measurements [13]. The system an operator may wish to deploy is dependent on the normal emissions rate of their asset. Of the 50 non-zero reporting assets in the 2022 EEMS dataset, 19 reported emissions rates higher than 2.5kg/h, and 43 reported rates higher than 0.5kg/h [14]. By performing frequent monitoring with a UAV, the hope is that a maximum abatement may be obtained by identifying leaks as quickly as possible and keeping the asset emissions rate below the sensor minimum detection threshold. This maximum abatement may be calculated by finding the difference between an asset's annual fugitive emissions, and the asset's annual emissions if the asset emitted at the minimum detection threshold of the drone used for monitoring. Again, the abatement calculated for this section is only a *maximum applicable abatement*, an operator must be proactive about finding the source of detected leaks and fixing them in order to receive any abatement from RAS deployment for methane monitoring. The reference table below demonstrates minimum thresholds and standoff distances for current drone monitoring technologies.

Table 18: Current methane monitoring RAS system specifications

RAS system	Minimum detection threshold (kg/h)	Standoff distance(m)
Rotary drone	0.5	50
Fixed wing (close)	2.5	250
Fixing wing (far)	10	500
Source: Smith et al., 2021		

Equation 23: Maximum applicable annual carbon abatement from drone methane monitoring

$$Annual_{abatement(max)} = (fugitives_{current(kg/h)} - detection\_threshold) * 24 * 365$$

Concluding Remarks

1 Source review

All sources selected for use in this report were screened for credibility in order to ensure the veracity of report results. Interviews and discussions were held with individuals from various backgrounds at major offshore energy providers. The information from these primary sources was used to inform as much of the technical day-to-day operation assumptions made in this report as possible. Some interviewees also granted OLTER access to operations data, which was anonymized and integrated into report calculations. Data provided by interviewees and information gleaned from interviews is asserted to be credible. Many conversion factors and other numbers contained in this report were also taken from UK government reports and datasets. DESNZ and EEMS data, in particular, were used very frequently within this report [2] [14]. These are numbers recognised by UK regulators and hence there is a sound base from which to calculate individual cases. Outside of the UK, Swiss and EU regulations and reports were also used to inform the calculations for this report [3] [4] [5]. These European data sources were particularly relevant for calculating the emissions of helicopter usage, as DESNZ does not contain any relevant conversion factors for this case. Data sourced from European governments is also asserted to be credible, and should satisfy regulators. Some data from British organizations such as the Energy Savings Trust (EST) and OEUK was also used [9] [15]; this data is seen as credible as EST was sponsored by the Department for Environment, Food, & Rural Affairs for their report, and OEUK is directly integrated with the offshore energy industry. Finally, data was taken from academic sources such as SPE papers and other papers from credible journals [6] [7] [8] [11] [12] [13]. It is hoped that the credibility of these sources is sufficient to inspire trust in conversion factors and calculations provided in this report.

2 OLTER’s role in RAS carbon abatement

The primary goal of OLTER is to increase RAS uptake in the offshore energy sector by removing market barriers. As is clear from this report, there is potential for RAS-induced carbon abatement almost everywhere within the industry. Through market analysis, it can be seen that OLTER’s success can directly impact the level of carbon abatement which could be achieved by the industry. OLTER’s market research has demonstrated that OLTER has the potential to increase land-based inspection and monitoring RAS uptake by up to 27.5%. BEIS reports have indicated that the best-case percentage of offshore tasks which may be performed by RAS is 39% [1], and Offshore Energies UK’s (OEUK) workforce insight report claims that at any one time, roughly 11,500 workers are living offshore at any given time [15]. Applying some very conservative assumptions within a POB reduction calculation with these figures, OLTER’s success could lead to an increased abatement of 17.7kt CO2e annually through optimized POB alone. This does not include other potential abatement categories which have significantly greater potential for abatement such as reduction in emergency maintenance flights to NUFs or usage of AUVs for inspection, maintenance, and repair of subsea equipment. As such, the OLTER project and RAS uptake in general can provide industry significant support in meeting climate goals.

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Appendix

1 Reference table of report results

Table A-1: Reference table of report results

Estimated annual abatement from optimized POB assuming full offshore RAS uptake (40%)		25 kt CO2e	
Optimized POB scenarios (1 asset)	**Potential Abatement (CO2e annually)**	**Cargo shipment emissions figures**	**Helicopter (CO2e/flight) – averaged, round-trip**
1 reduction	4.410 t CO2e @50nm		1650 kg CO2e @ 50nm
	7.936 t CO2e @100nm		2813 kg CO2e @ 100nm
	14.99 t CO2e @200nm		5138 kg CO2e @ 400nm
5 reductions	37.18 t CO2e @ 50nm		**PSV (CO2e/tonne of cargo) – (≈1500t deadweight) @ ECO Speed**
	54.76 t CO2e @100nm		2.643 kg CO2e @ 50nm
	86.39 t CO2e @200nm		5.286 kg CO2e @ 100nm
19 reductions	36.36 t CO2e @ 50nm		10.57 kg CO2e @ 200nm
	64.91 t CO2e @ 100nm		**PSV (CO2e/tonne of cargo) – (≈4500t deadweight) @ ECO Speed**
	116.3 CO2e @ 200nm		
Additional POB	**POB reduction (person/year)**		3.851 kg CO2e @ 50nm
Custodial (Varies based on rig contract)	Avg. 1 extra POB reduction per 10 core team reduced (<100 POB)		7.702 kg CO2e @ 100nm
	Avg. 1 extra POB reduction per 15 core team reduced (>100 POB)		15.4 kg CO2e @ 200nm

2 Reference equations derived from report results

Equation 1: Annual abatement from flights for a POB reduction n (km)

$$Abatement_{annual}(n) = n(Shetlands\_dist\_km_{2-way} * 0.27258 * num\_flights_{annual})$$

Equation 2: Annual abatement from flights for a POB reduction n (mi)

$$Abatement_{annual}(n) = n(Shetlands\_dist\_mi_{2-way} * 0.43867 * num\_flights_{annual})$$

Equation 3: Annual abatement from individual helicopter declassing

$$Abatement_{annual} = num\_flights_{annual}(distance_{asset(2-way)} * \big(emissions_{cruise(old-heli)} - emissions_{cruise(new-heli)}\big) + 2 * (emissions_{LTO(old-heli)} - emissions_{LTO(new-heli)}))$$

Equation 4: Annual abatement from individual helicopter usage reductions

$$Abatement_{annual} = flights\_reduced_{annual}(distance_{asset(2-way)} * emissions_{cruise} + 2 * emissions_{LTO})$$

Equation 5: Annual abatement from food consumption for a POB reduction n

$$Abatement_{annual}(n) = n(1.095 * conversion\_factor\ * distance_{asset(2-way)})$$

Equation 6: Annual abatement from water consumption for a POB reduction n (no desalination)

$$Abatement_{annual}(n) = n(31.6 * conversion\_factor * distance_{asset(2-way)})$$

Equation 7: Combined annual abatement for a POB reduction n

$$Abatement_{annual}(n) = emissions_{transport}(n) + emissions_{food}(n) + emissions_{water}(n)$$

Equation 8: Annual abatement for reduction in emergency trips to an asset

$$Abatement_{annual} = trips\_reduced_{annual} * (emissions_{cruise} * distance_{asset(2-way)} + 2 * emissions_{LTO})$$

Equation 9: Annual abatement from reducing supply vessel trips to asset

$$Abatement_{annual} = reduced\_trips_{annual} * conversion\_factor * distance_{asset,2-way}$$

Equation 10: Annual abatement from reducing tonnage of supply vessel for an asset

$$Abatement_{annual} = trips_{annual} * (conversion\_factor_{old-vessel} - conversion\_factor_{new-vessel}) * distance_{asset(2-way)}$$

Equation 11: Annual abatement from reducing supply vessel trips and tonnage of supply vessel for an asset

$$
\begin{aligned}
&Abatement_{annual} \\
&\quad = reduced\_trips_{annual} * conversion_{factor_{old}} * distance_{asset,2-way} \\
&\quad + declassed\_trips_{annual} * (conversion\_factor_{old-vessel} - conversion\_factor_{new-vessel}) \\
&\quad * distance_{asset(2-way)}
\end{aligned}
$$

Equation 12: Annual abatement from reduced supply vessel emergency deliveries for a given asset

$$
Abatement_{annual} = reduced\_trips_{annual} * conversion\_factor * distance_{asset(\,2-way)}
$$

Equation 13: Annual abatement from reduced helicopter emergency deliveries to asset

$$
Abatement_{annual} = reduced\_trips_{annual}(emissions_{cruise} * distance_{asset(2-way)} + 2 * emissions_{LTO})
$$

Equation 14: Annual abatement from reduced normal helicopter deliveries

$$
Abatement_{annual} = reduced\_trips_{annual}(emissions_{cruise} * distance_{asset(2-way)} + 2 * emissions_{LTO})
$$

Equation 15: Annual abatement from declassing of helicopters for scheduled deliveries

$$
\begin{aligned}
&Abatement_{annual} \\
&\quad = declassed\_trips_{annual}[(emissions_{cruise(old-heli)} - emissions_{cruise(new-heli)}) \\
&\quad * distance_{asset(2-way)} + 2 * (emissions_{LTO(old-heli)} - emissions_{LTO(new-heli)})]
\end{aligned}
$$

Equation 16: Annual abatement from declassing of helicopters and reduced cargo flights for normal deliveries

$$
\begin{aligned}
&Abatement_{annual} \\
&\quad = reduced\_trips_{annual}(emissions_{cruise(old-heli)} * distance_{asset(2-way)} + 2 \\
&\quad * emissions_{LTO(old-heli)}) \\
&\quad + declassed\_trips_{annual}[(emissions_{cruise(old-heli)} - emissions_{cruise(new-heli)}) \\
&\quad * distance_{asset(2-way)} + 2 * (emissions_{LTO(old-heli)} - emissions_{LTO(new-heli)})]
\end{aligned}
$$

Equation 17: Annual abatement from RAS deployment for pipeline surveying (One vessel)

$$
\begin{aligned}
&Abatement_{annual} \\
&\quad = surveys_{annual}(length_{pipeline/survey} * conversion\_factor + distance_{pipeline(2-way)} \\
&\quad * conversion\_factor)
\end{aligned}
$$

Equation 18: Annual abatement from RAS deployment for subsea tieback survey (One vessel)

$$
\begin{aligned}
&Abatement_{annual} \\
&\quad = steam\_time_{annual} * conversion\_factor + survey\_time_{per-tieback} \\
&\quad * tiebacks\_surveyed_{annual}
\end{aligned}
$$

Equation 19: Carbon abatement from vessel improvement in the tonnage domain (conversion factors)

$$
Abatement_{annual} = (consumption_{old} - consumption_{new}) * conversion\_factor * travel\_distance_{annual}
$$

Equation 20: Carbon abatement from vessel improvement in the emissions reduction domain (conversion factors)

$$Abatement_{annual} = \%reduction_{emissions} * conversion\_factor * travel\_distance_{annual}$$

Equation 21: Carbon abatement from vessel improvement in utilization reduction domain

$$Abatement_{annual} = reduction_{utilization} * conversion\_factor$$

Equation 22: Carbon abatement from vessel improvement in all domains

$$\begin{aligned} Abatement_{annual} \\ &= reduction_{utilization} * conversion\_factor_{old-vessel} + utilization_{new} \\ &\quad * (conversion\_factor_{old-vessel} - conversion\_factor_{new-vessel}) \\ &\quad + \%reduction_{emissions}(utilization_{new} * conversion\_factor_{new-vessel}) \end{aligned}$$

Equation 23: Maximum applicable annual carbon abatement from drone methane monitoring

$$Annual_{abatement(max)} = (fugitives_{current(kg/h)} - detection\_threshold) * 24 * 365$$