Introduction

This report is a summary of the updated preliminary Best Available Techniques (BAT) assessment for Wormington Compressor Station[1]. The assessment was updated using investment options identified in the FEED Feasibility Study and National Grid Cost Benefit Analysis (CBA). Its purpose is to support decision making and accompanies the Final Option Selection Report (FOSR), to demonstrate the investment case for an upgrade at Wormington Compressor Station.

Investment is required for the site to comply with the requirements of the Medium Combustion Plant Directive (MCPD) and anticipated future gas flows. The assessment has been undertaken independently from the CBA Tool analysis using a different methodological approach[2]; it does however incorporate common assumptions on cost and future gas supply predictions.

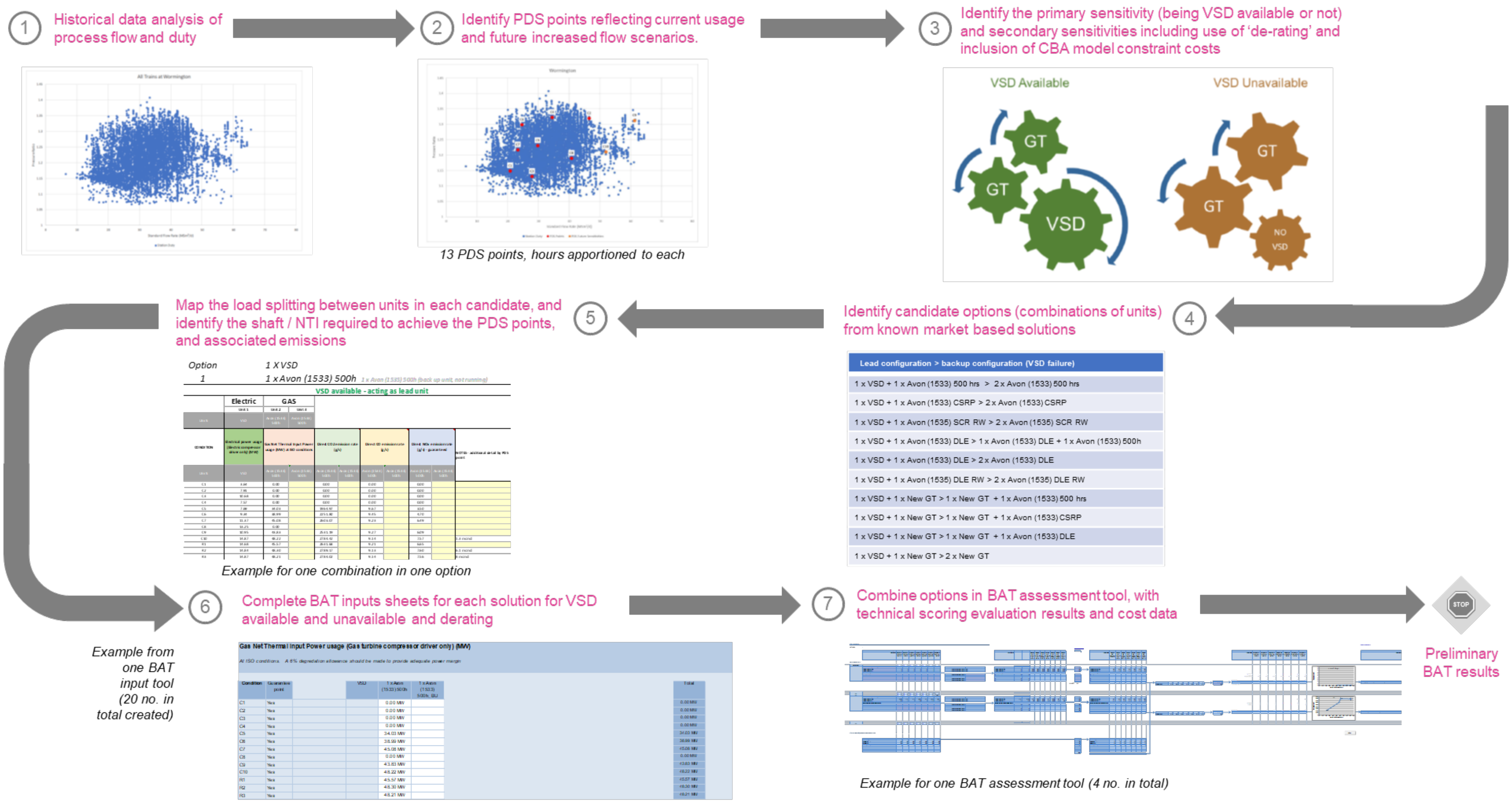
This is a preliminary assessment informed by the engineering study, engine testing and cost estimates described in the FOSR. The BAT assessment will be updated at the project procurement stage, with information provided by equipment suppliers (OEMs).

BAT methodology overview

The BAT assessment approach is a stepwise process underpinned by an environmental cost-benefit analysis methodology, which draws together environmental and operational priorities to support decision making. It has been used to assess different gas compressor unit combinations ('BAT candidate options') that could potentially be used to deliver future process condition requirements at Wormington. Figure 1, overleaf, illustrates the key steps within the BAT assessment.

[1] Early preliminary BAT assessment summary report provided with the RIIO-2 Business Plan, 2019
[2] As defined in National Grid Specification Procedure T/SP/ENV/21 (v2) Specification for Best Available Techniques (BAT) assessment for Compressor Machinery Train

Figure 1 Wormington preliminary BAT assessment, method overview



Key features of the BAT models

The following summarises the key features of the BAT model:

- The models are populated with data validated by the business on process conditions, capital costs and maintenance costs.
- Representative business stakeholders identified the following technical/environmental criteria used to qualitatively score the options and the weighting applied to each criterion. Collectively these criteria have a weighting of 65% of the total combined technical and environmental scores.

Qualitative Criteria Description (Technical & Environmental)	Weighting
Versatility - extent and useability of an MCPD emissions compliant compressor envelope	15%
Future proofing – headroom above current emission limits and performance against anticipated energy efficiency levels which may be contained in a future MCPD BAT Reference Document (BREF)[3]	15%
Ownership - maintenance complexity and availability of spares for the compressor plant	13%
Constructability – ease of construction and likely disruption to existing site operations	7%
Environmental amenity – potential for visual and noise concerns	10%
Hazard - remaining environment risks	5%
	65%

- Oxides of nitrogen (NOx), carbon dioxide (CO_2) and carbon monoxide (CO) emissions are quantitatively evaluated and scored, based on predicted emissions and have a weighting of 35% overall.
- The BAT model assesses a 20-year period, over which total emissions and whole life operating costs (including fuel) are calculated. The time period for this Wormington assessment is nominally 2026-2046. Although this is a different time period than the CBA assessment, it is not anticipated this will have a material impact on the results. Capital costs are rebased to FY18/19 in line with the CBA requirements for consistency.

[3] The UK environmental agencies have indicated that any forthcoming BREF for MCDP will contain energy efficiency targets.

Future Process Duty Specification (PDS) points and running hours

The BAT assessment was undertaken on the potential compressor configuration options (referred to from now on as 'candidate BAT Options') identified for Case 3 only. Case 3 comprises PDS points that represent the MCPD requirement (i.e. continuation of historical operation) plus an increase in gas flows as a result of the planned Western Gas Network (WGN) Project, which includes pipeline reinforcement from Wormington to Honeybourne.

An additional limitation on this Case is that lead compression capability cannot exceed 30MW, (i.e. compressor investment to replace the existing Avon gas turbines cannot exceed 15 MW shaft power per compressor train to prevent Large Combustion Plant Directive constraints (LCPD))[4]. The table below illustrates Case 3 PDS points and estimated running hours, with points C1-C10 representing the MCPD requirement and R1-R3 the requirement as a result of the WGN Project. The total running hours for the Basis of Design for the site are estimated as 3,250 hours in the BAT assessment.

Duty	Station Flow (mcmd)	Station Inlet Temp (deg C)	Unit Inlet Pressure (barg)	Unit Outlet Pressure (barg)	Running Hours/Year (est. 2030)
C1	18.00	13.55	53.26	62.67	353
C2	58.57	4.85	66.61	74.92	235
C3	39.71	6.28	54.41	68.00	588
C4	21.87	7.51	50.89	68.29	294
C5	40.59	7.40	51.36	69.75	529
C6	68.70	2.62	55.11	69.37	59
C7	60.60	5.41	54.50	74.18	235
C8	29.25	10.39	46.53	66.42	118
C9	48.05	8.63	47.61	68.32	60
C10	61.46	2.70	47.77	69.14	29
R1	58.33	0.07	40.75	58.74	245
R2	62.56	-5.40	44.40	66.63	392
R3	73.54	2.37	49.40	69.55	113

[4] For a unit to be a MCP it must have a thermal input of <50MW; units with a shaft power of more than 15MW are likely to have a higher thermal input and would be classed as LCP and have energy efficiency levels (and additional emission limit values) imposed by the environmental regulator.

Identification of candidate BAT options

The engineering study identified compressor investment options for Wormington. Options included:

- The ‘counterfactual’ of no changes to the units aside from ‘re-lifing’ (where Avon units will be restricted to 500 hours running per annum under the MCPD derogation).
- Retaining the current Avon units but installing Control System Restricted Performance (CSRP) to restrict power to a level where the MCPD NOx emission limit cannot be breached.
- The installation of retrofit DLE technology to the Avons (engine model 1533).
- The installation of retrofit DLE technology to the Avons plus uprating the Avon from model 1533 to model 1535 to provide additional power but restricting it to a rated thermal input of <50MW, to avoid requirement to meet the LCPD.
- The installation of retrofit Selective Catalytic Reduction (SCR) equipment to an uprated 1535 spec Avon (although still <50MW rated thermal input) to lower NOx emissions and bring it into compliance with the MCPD.
- The installation of new gas turbine (GT) units, either one or two, to replace the Avons. A single new GT unit would necessitate the retention of a retrofitted or derogated Avon.

BAT candidate options were developed based on the current Variable Speed Drive (VSD) electric compressor being available and unavailable as the lead unit. Options discounted in the engineering study for the BAT assessment were:

- An additional electric VSD.
- A single large GT.
- Combination of retrofit options (e.g. one Avon DLE and one Avon SCR).
- Deferred investment in a second new unit. This option has been assessed using the CBA tool based on an initial investment in Option 7 before installation of a second new unit resulting in an end state similar to Option 10 from 2035.

The following table summarises the lead and backup configurations considered in the BAT assessment.

Option Number	Lead configuration (VSD available)	Backup configuration (VSD unavailable)
Option 1	1 x VSD + 1 x Avon 500 hrs *(current equipment)*	2 x Avon 500 hrs *(current equipment)*
Option 2	1 x VSD + 1 x Avon CSRP	2 x Avon CSRP
Option 3	1 x VSD + 1 x Avon SCR (1535)	2 x Avon SCR (1535)
Option 4	1 x VSD + 1 x Avon DLE (1533)	1 x Avon DLE (1533) + 1 x Avon 500 hrs
Option 5	1 x VSD + 1 x Avon DLE (1533)	2 x Avon DLE (1533)
Option 6	1 x VSD + 1 x Avon DLE (1535)	2 x Avon DLE (1535)
Option 7*	1 x VSD + 1 x New GT	1 x New GT + 1 x Avon 500 hrs
Option 8*	1 x VSD + 1 x New GT	1 x New GT+ 1 x Avon CSRP
Option 9*	1 x VSD + 1 x New GT	1 x New GT+ 1 x Avon DLE (1533)
Option 10**	1 x VSD + 1 x New GT	2 x New GT

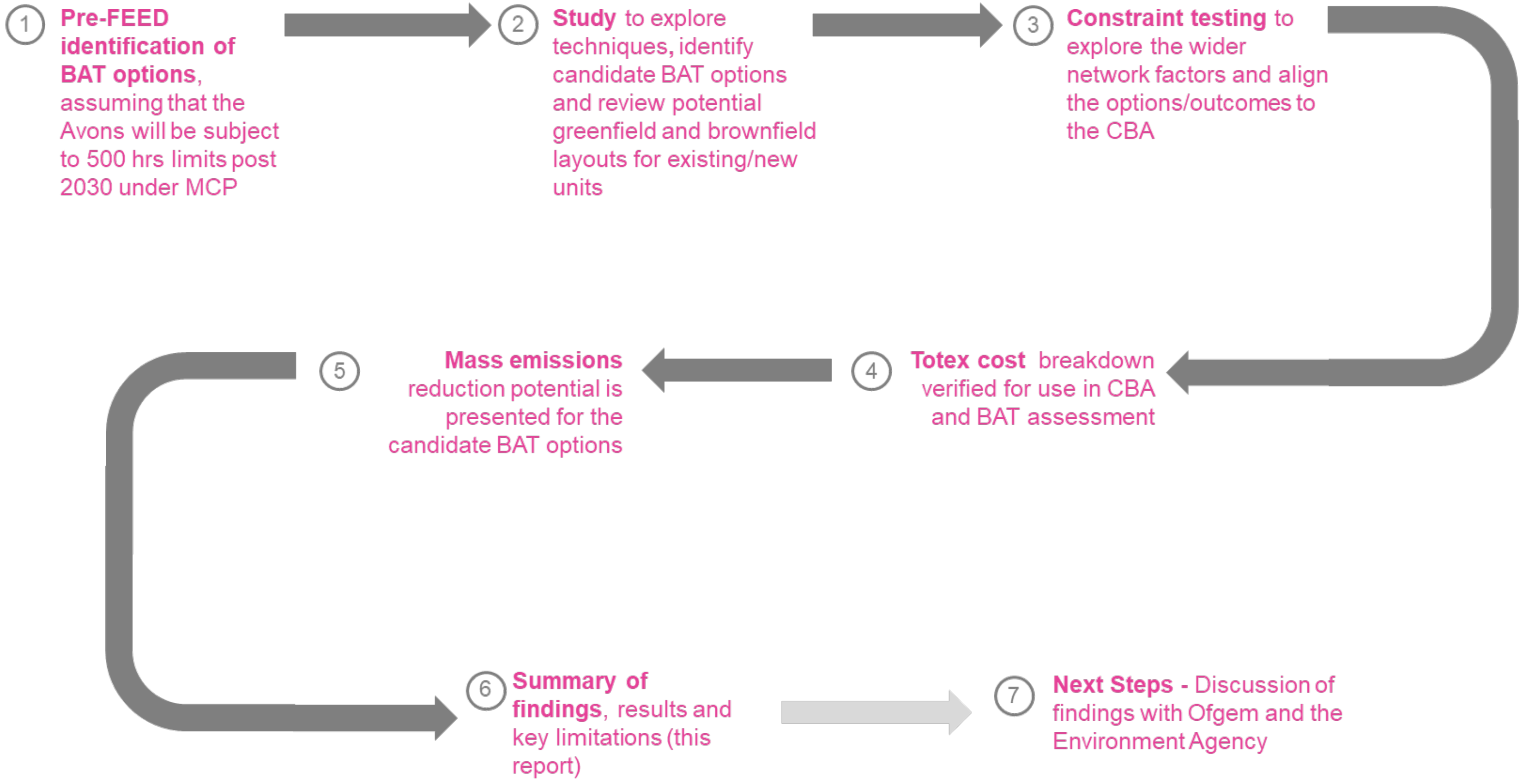
*Option includes decommission of 1 x Avon

**Option includes decommission of 2 x Avon

Stepwise approach to the BAT assessment

The flow chart below illustrates the phased approach to exploring the opportunities and constraints through the BAT assessment, in order to produce updated preliminary results on the candidate BAT options for Wormington.

Figure 2 Stepwise approach to BAT assessment and findings narrative



Qualitative Technical Scores for candidate BAT options

VSD Unavailable

The following table provides the technical/environmental qualitative criteria weighted percentage scores for each candidate BAT option for when the VSD is not operational. Derogated and restricted solutions (Options 1, 2 and 4) have the lowest scores for versatility and future proofing but score better in terms of constructability. These options (option 1, 2 and 4): have restricted running hours as a result of the Avon 500h derogation limit; have very restricted power availability; are already likely to exceed NOx limits under certain operational conditions or would not withstand a tightening of the NOx limit. Option 6, (2 x Avon DLE 1535 capped at 50 MWth, reducing maximum shaft power available but retaining MCP status) and Option 3 (2 x Avon SCR 1535) have greater energy efficiency than Option 5 (2 x Avon DLE 1533), therefore has a higher score for future proofing should efficiency be introduced as a requirement for MCP. Conversely, new GT based solutions score more highly in terms of versatility and future proofing but are more complex to build. The emission abatement solutions represent the middle ground, with DLE retrofits scoring more highly for constructability than SCR retrofit.

Option Number	Backup configuration (VSD unavailable)	Versatility	Future Proofing	Ownership	Constructability	Environmental amenity	Hazard	Total
Option 1	2 x Avon 500 hrs (current equipment)	0%	0%	10%	7%	10%	5%	32%
Option 2	2 x Avon CSRP	0%	0%	10%	7%	10%	5%	32%
Option 3	2 x Avon SCR (1535)	6%	9%	5%	0%	6%	2%	28%
Option 4	1 x Avon DLE (1533) + 1 x Avon 500 hrs	0%	0%	8%	6%	10%	5%	28%
Option 5	2 x Avon DLE (1533)	6%	6%	8%	6%	10%	5%	40%
Option 6	2 x Avon DLE (1535)	9%	9%	8%	6%	10%	5%	46%
Option 7	1 x New GT + 1 x Avon 500 hrs	3%	0%	10%	4%	6%	5%	29%
Option 8	1 x New GT+ 1 x Avon CSRP	9%	0%	10%	4%	6%	5%	35%
Option 9	1 x New GT+ 1 x Avon DLE (1533)	12%	9%	8%	4%	6%	5%	44%
Option 10	2 x New GT	15%	15%	13%	4%	2%	5%	54%
Maximum weighted score available (65%)	N/A	15% / 65%	15% / 65%	13% / 65%	7% / 65%	10% / 65%	5% / 65%	*65%*

VSD Available

The following table provides the technical/environmental qualitative criteria weighted percentage scores for each candidate BAT option for when the VSD is available. The scoring themes are similar to the 'VSD Unavailable' scenario above, the primary difference being that with the 'VSD available' the versatility of the single new GT options improves as there is no reliance on the Avon-based back-up solutions.

Option Number	Backup configuration (VSD available)	Versatility	Future Proofing	Ownership	Constructability	Environmental amenity	Hazard	Total
Option 1	2 x Avon 500 hrs (current equipment)	0%	0%	10%	7%	10%	5%	32%
Option 2	2 x Avon CSRP	0%	0%	10%	7%	10%	5%	32%
Option 3	2 x Avon SCR (1535)	9%	9%	5%	0%	6%	2%	31%
Option 4	1 x Avon DLE (1533) + 1 x Avon 500 hrs	9%	6%	8%	6%	10%	5%	43%
Option 5	2 x Avon DLE (1533)	9%	6%	8%	6%	10%	5%	43%
Option 6	2 x Avon DLE (1535)	12%	9%	8%	6%	10%	5%	49%
Option 7	1 x New GT + 1 x Avon 500 hrs	15%	15%	13%	4%	6%	5%	58%
Option 8	1 x New GT+ 1 x Avon CSRP	15%	15%	13%	4%	6%	5%	58%
Option 9	1 x New GT+ 1 x Avon DLE (1533)	15%	15%	13%	4%	6%	5%	58%
Option 10	2 x New GT	15%	15%	13%	4%	2%	5%	58%
Maximum weighted score available	N/A	15% / 65%	15% / 65%	13% / 65%	7% / 65%	10% / 65%	5% / 65%	*65%*

BAT Results

Avons at Wormington would be subject to the existing unit requirements of the MCPD due to their NOx emissions exceeding 150 mg/Nm^3. As such, for the Avons to form part of a viable site solution, they would need to operate within the 500 hours derogation limit post 2030. Alternatively, Avon emissions would need to be restricted using CSRP or emissions mitigated using retrofit DLE or SCR techniques. It is assumed that the VSD will continue to be the lead unit in the future running of the compressor station. The VSD would run with one other unit to meet all or part of the compression requirements of Case 3.

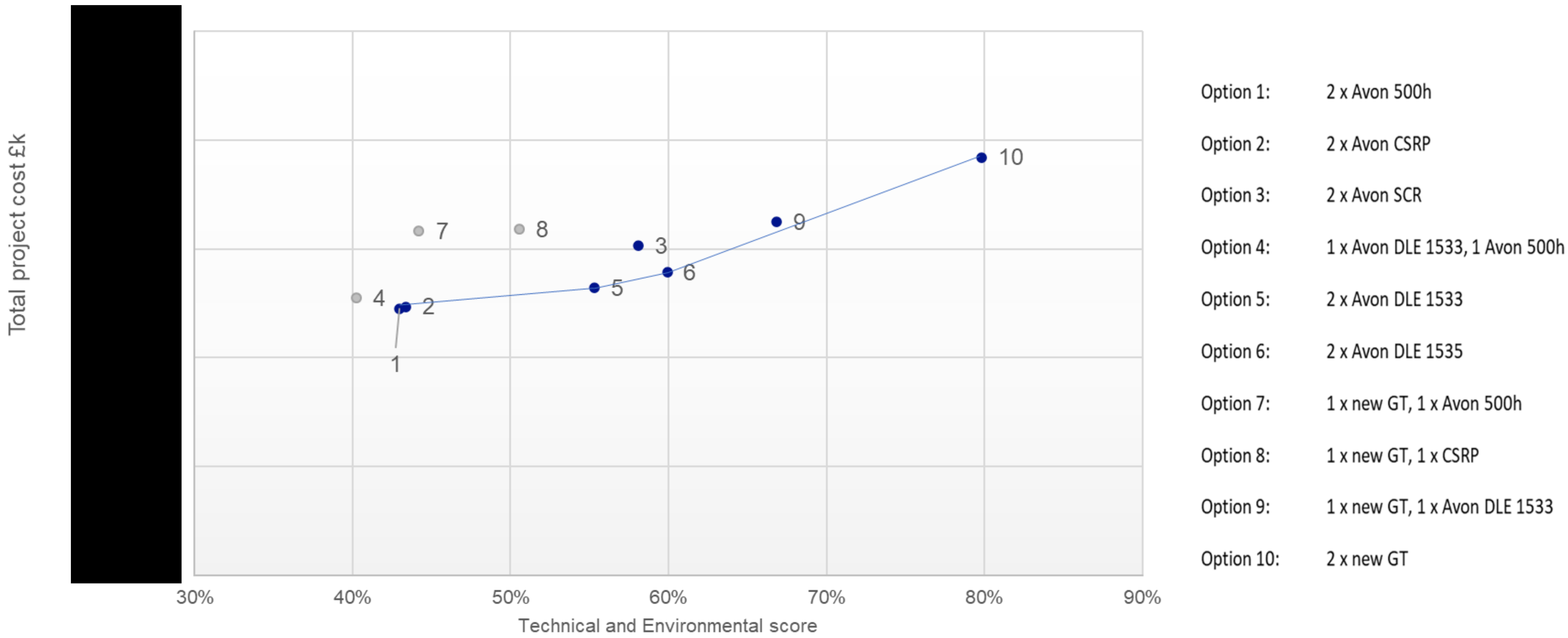
Based on the modelled annual site running hours and operating conditions, all options that utilise an Avon 1533 (and to a lesser extent an Avon 1535) cannot achieve all of the PDS points in Case 3, resulting in a shortfall in compression capacity. This shortfall is reflected in the scoring of the versatility criterion in this stage of the assessment but has a greater influence later when considered with potential constraint costs which could be incurred.

The first two charts illustrate the cost-benefit BAT model results. The Y axis represents the modelled total project cost over the next 20 years; the X axis is the combined technical and environmental score derived by the BAT model for the options.

BAT appraisal – VSD unavailable

When the VSD is unavailable, compression capability will be provided by the unit that usually supports the VSD plus the back-up unit. The chart below illustrates the BAT results for when the VSD is not operational.

Figure 3   BAT – future operations; VSD unavailable



Key observations from the assessment are as follows:

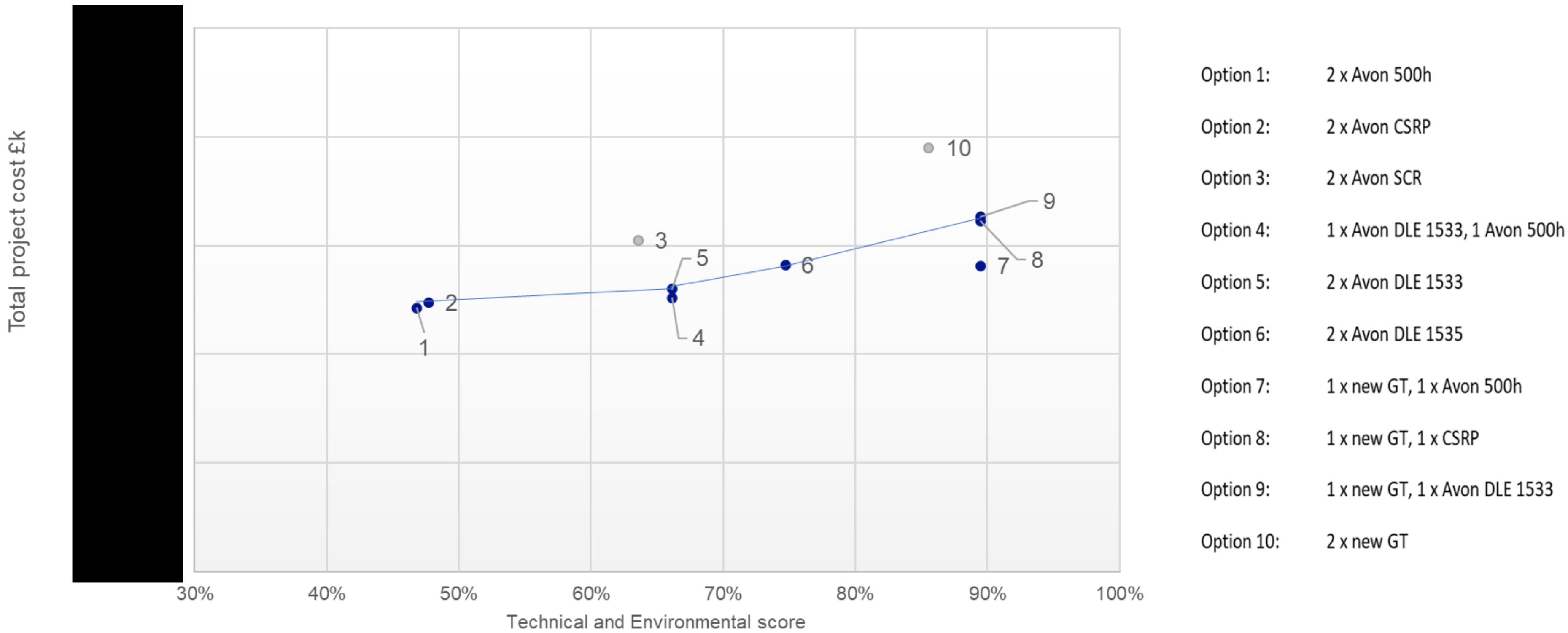
- The chart illustrates that all options that retain an unmitigated Avon (Options 1, 2 and 4) have the lowest technical/environmental score. These options have higher emissions and score low for future proofing[5]. Consequently, although options 7 and 8 include a new GT, they contain either an unabated Avon on 500h or an Avon CSRP unit, which will be required to run if the VSD is unavailable (with associated higher emissions as a result), these options offer a poor cost-benefit for this reason.
- Options 3, 5 and 6 form a cluster of solutions that have similar costs and technical/environmental performance. They all offer at least 10% points performance gain on options that contain an unmitigated Avon. Any of these options could potentially be a BAT solution in isolation (without factoring in potential network constraints) given that this is a back-up case. However, site footprint requirements are likely to make the construction of SCR on both Avons unfeasible at Wormington.
- Option 9, which combines a new unit with a mitigated Avon 1533 DLE, offers the potential for a material gain in environmental/technical performance, which is matched by an equivalent increase in cost. As will be noted later, this option performs well in the 'VSD available' case too. Although Option 10 is estimated to cost an estimated [redacted] more in whole life costs compared to Option 6, this does achieve considerably more environmental/technical gain over all options that retain an Avon unit (at least 20% points more). The cost increment from Option 9 to Option 10 is lower at approximately £ [redacted] over the whole project life.
- In considering the conclusions in this section, it should be noted that this is the VSD unavailable scenario which would be expected to occur during less than 25% of the running period. It is however, of importance in the investment decision as it is under unavailability scenarios that the site operations would be under greatest pressure to undertake required duty and remain in legal compliance.

[5] Scoring of the future proofing scoring was undertaken on the lowest performing unit in the option.

BAT appraisal – VSD available

The VSD is the lead unit when it is operational, with one other unit running to meet all or part of the compression requirements of Case 3. The second chart illustrates the BAT results for when the VSD is available.

Figure 4 BAT – future operations; VSD available



Key observations from the assessment are as follows:

- The chart illustrates that Option 1, which represents the current site configuration, has the lowest estimated whole life cost but also has the lowest technical/environmental score. Poor versatility, no future proofing and high NOx emissions contribute to this. For the expected running hours for the PDS points of Case 3, the Avons would exceed 500 hours per year of operation, making this option unable to deliver the expected compression requirements.

- Option 2 using CSRP also has a low overall performance; the reduction in power caused by CSRP is expected to limit the available compressor envelope and reduces compression capability. The technique only provides regulatory compliance with the emission limits of the MCPD and does not result in any material reduction in emissions, therefore total NOx emissions are similar to an unabated Avon, contributing to a lower technical/environmental performance compared to options with emissions abatement techniques/new GT.

- The options that include investment in emissions abatement techniques of SCR and retrofit DLE on both Avon units achieved a higher performance score. Option 6 using Avon DLE 1535 was the best performing due to increased versatility but is slightly more costly due to power upgrade/compressor rewheel requirements.

- Option 3 SCR has a slightly higher whole life cost compared with the Avon DLE options and scored less for ease of construction, reducing the environmental/technical score; this can be considered an outlier as lower cost, higher performing options are available. It should be noted though that retrofitting SCR solutions to gas turbines (including Avons), is proven in use, whereas the other retrofit solutions considered in this BAT study cannot yet demonstrate real world applications, but nonetheless they are assumed to be available at this stage.

- All options that include a single new GT (which is assumed to run with the existing VSD, in preference to the remaining Avon) offer considerable environment/technical gain. Avon usage would be relegated to back-up only under all scenarios when the VSD is available. The two new GT option is more costly with a slightly reduced environmental/technical score as a result of constructability, when considered in isolation (without taking account of circumstances when the VSD is unavailable, or constraints costs, both of which are considered later in this assessment) investing in a second new machine adds cost, but no environmental / technical benefit.

Constraint testing

The CBA calculates constraint costs to accommodate circumstances when the units are unavailable. These include penalties placed on the business such as buying gas on the day or buying back capacity from end users. These costs apply to all of the PDS Cases assessed by the CBA and include risk factors associated with capability of the site and techniques within the options. In addition, when the VSD is the lead unit, all the options that utilise an Avon (Options 1 to 6) are unable to meet all of the PDS points associated with Case 3. When the VSD is unavailable, only the 2 x new GT option can fully meet all of the PDS points. This shortfall in capacity has been factored into the constraint costs.

Typically, constraint costs are excluded from the initial stages of the BAT assessment but are added in where relevant as a sensitivity. With Wormington being a strategically critical site (supporting entry flows from the Milford Haven Aggregated System Entry Point (ASEP)) and to aid comparison with the CBA, a sensitivity assessment was undertaken on the candidate BAT options through inclusion of the constraints costs in order to take into account these wider network factors. The addition of constraint costs has a material influence on the BAT results and should be a significant factor in investment decision making.

Figure 5 illustrates the addition of constraint costs in the BAT assessment when the VSD is unavailable. It can be observed that, with the addition of constraint costs, Option 10 (two new GTs) has the highest technical/environmental performance at the lowest whole life cost. The inset chart includes Option 1 (2 x 500h) illustrating the very high constraint costs associate with this case, the main chart presents the remaining options only with an adjusted Y-axis scale.

Figure 5 BAT – future operations; VSD unavailable; with constraint costs

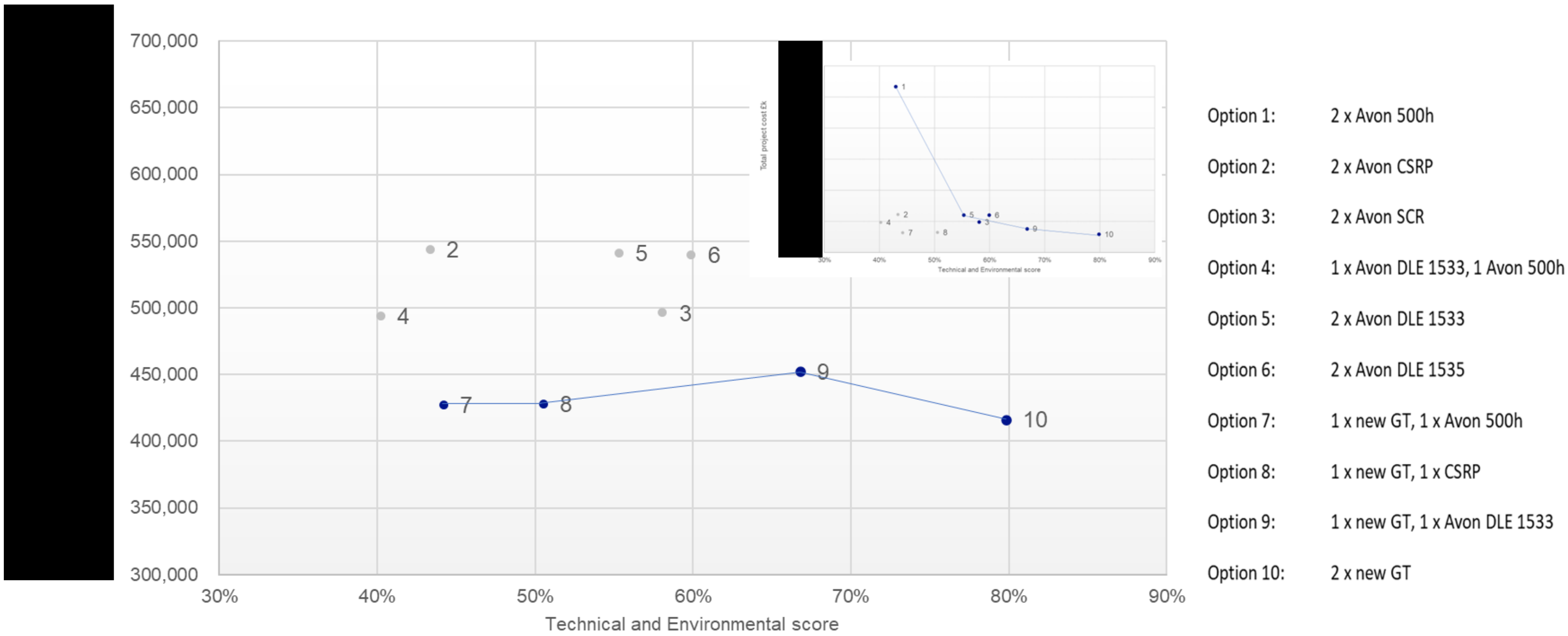


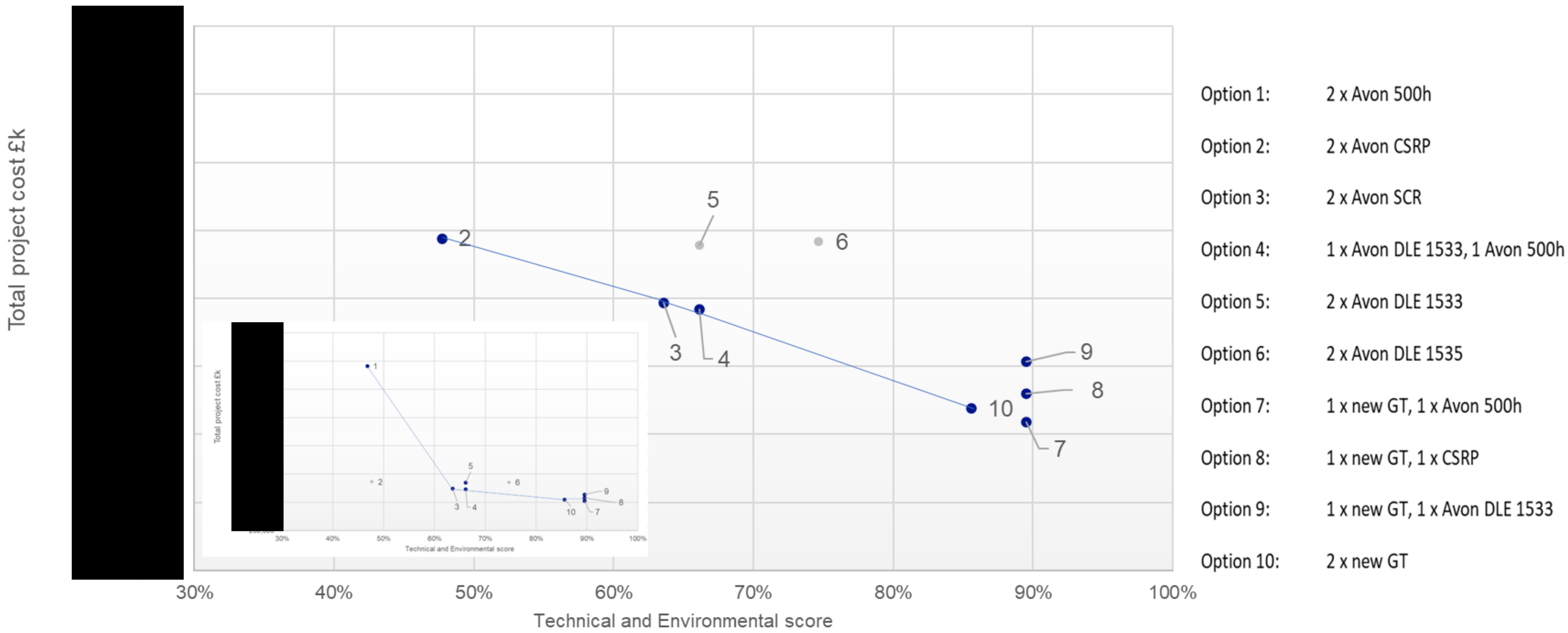
Figure 6 illustrates the BAT assessment for when the VSD is available, the follow observations can be made:

- The addition of constraint costs highlights the very substantial network costs associated with the counterfactual ("do nothing") base case, and is significantly more costly than all other options. All investment options therefore offer a degree of gain at a lower whole life, risk adjusted cost, with greater potential environmental/technical gain arising though each option with only modest whole life cost changes.

- Options that include at least one new GT (Option 7, 8, 9 and 10) are clustered together on the chart and have a lower total project cost than options that are based solely on Avon abatement techniques.

The inset chart includes Option 1 (2 x 500h) illustrating the very high constraint costs associate with this case, the main chart presents the remaining options only with an adjusted Y-axis scale.

Figure 6 BAT – future operations; VSD available, with constraint costs



Totex cost

The total whole life modelled cost (totex) breakdown for the 20-year period of the BAT model is explored for the candidate BAT options to show the breakdown of key cost components, rounded to the nearest hundred pounds. Charts are provided without/with the VSD available (no constraint costs).

Key points to note when interpreting these charts are as follows:

- The BAT model uses a simplified spend profile for total installed costs so discounted costs will not completely align to the CBA, however they are not materially different. The same UK Government Green Book discounting factor of 3.5% is used in the CBA and the BAT model.
- The maintenance costs are for a 20-year period whereas the CBA runs until 2050, hence maintenance costs will appear lower in the BAT model outputs.
- Gas and electricity prices are based on published data, with the same source data used in the CBA and BAT model[6].
- Derived remaining operating costs for Option 3 relate to replacement of the SCR catalyst.

The charts illustrate that total energy costs are reasonably comparable, irrespective as to whether the VSD is operating or not. For the new single GT options, package capex costs comprise approximately 45% of total project cost. A second GT adds on an additional 8% cost to total project costs. Maintenance costs (ongoing asset health and overhauls) are estimated to be higher for options including Avon units. When the VSD is not operating, fuel is the highest cost component of total project costs for options with two Avon units.

[6] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019

Figure 7 VSD unavailable

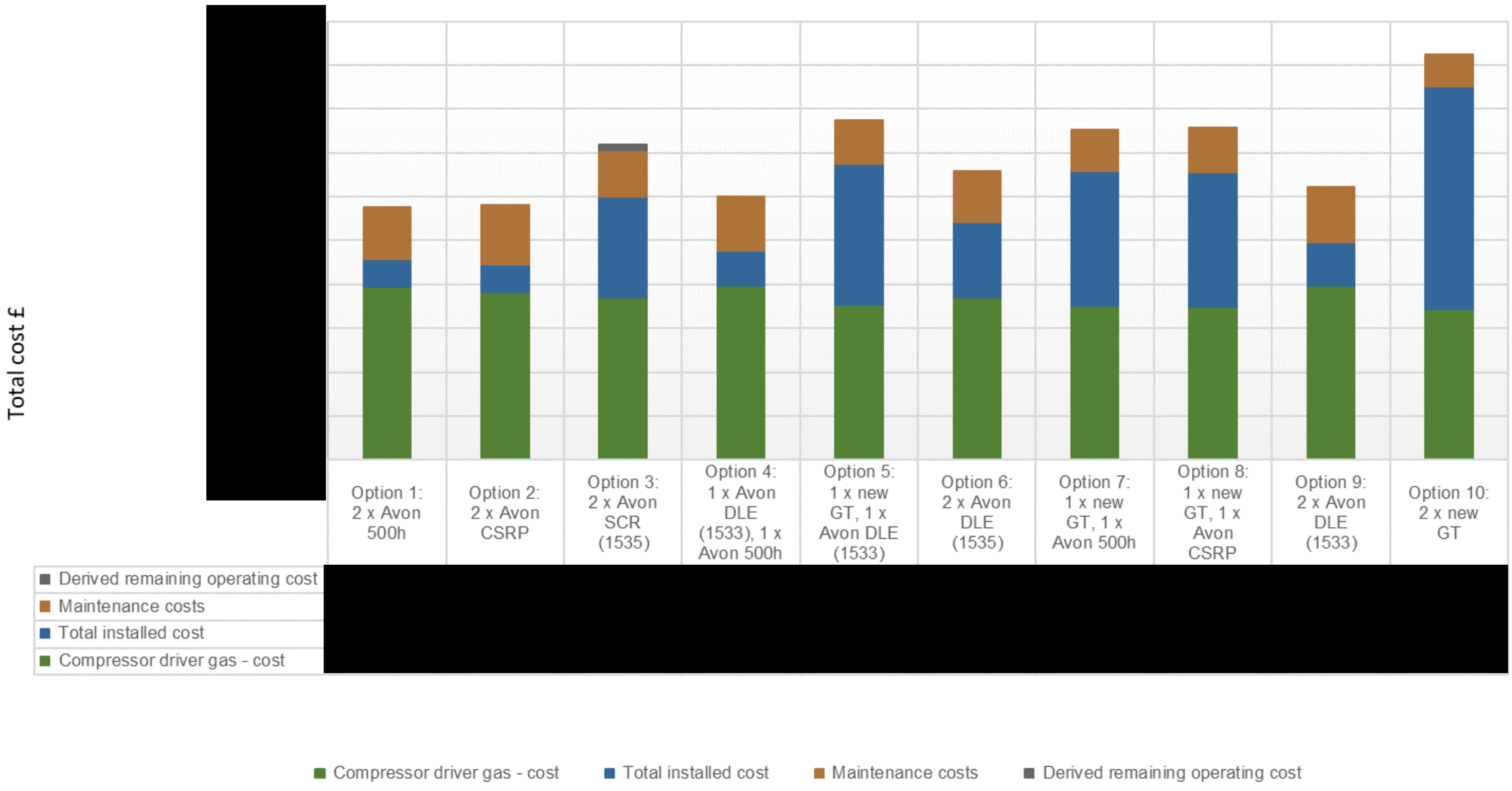
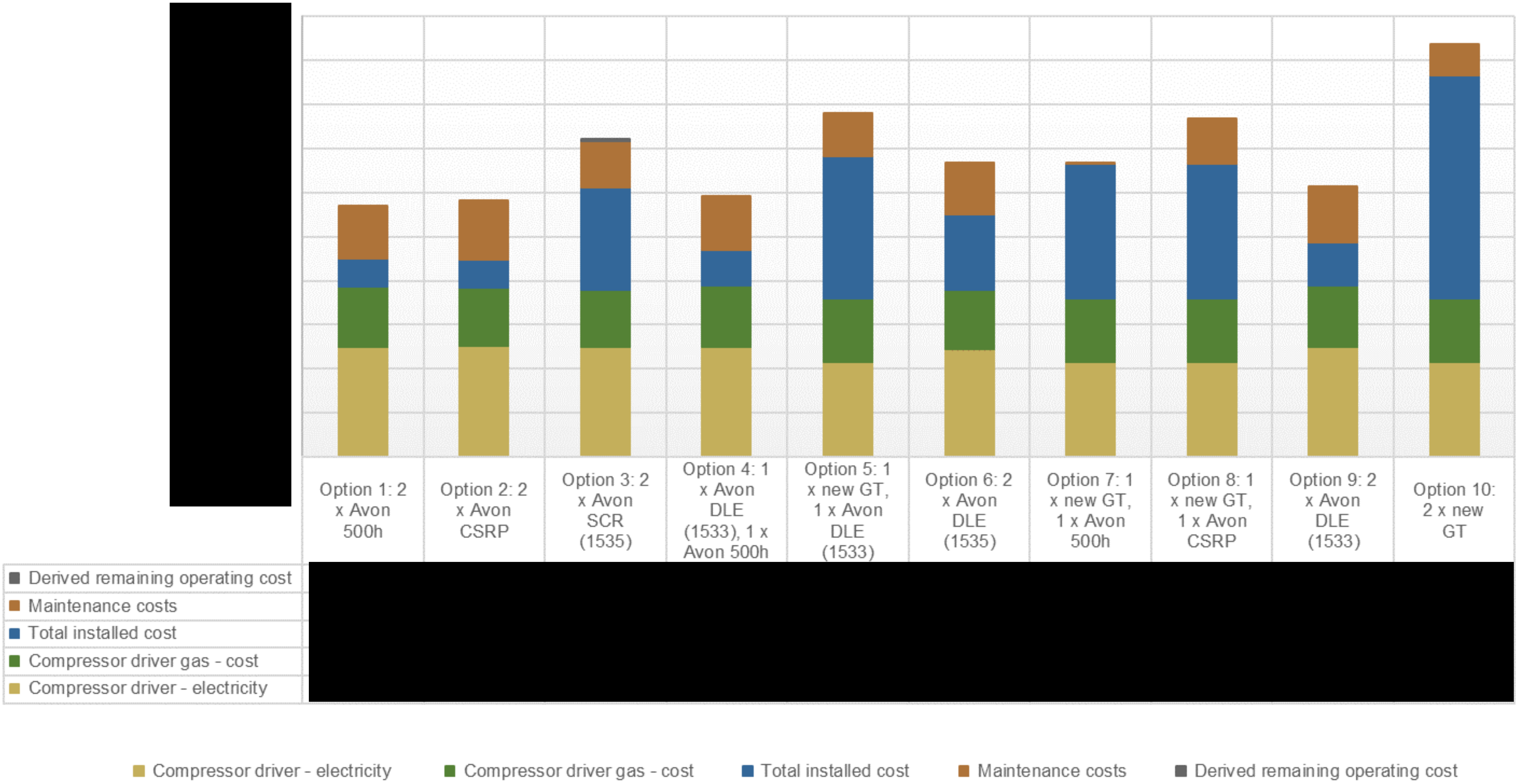


Figure 8 VSD available

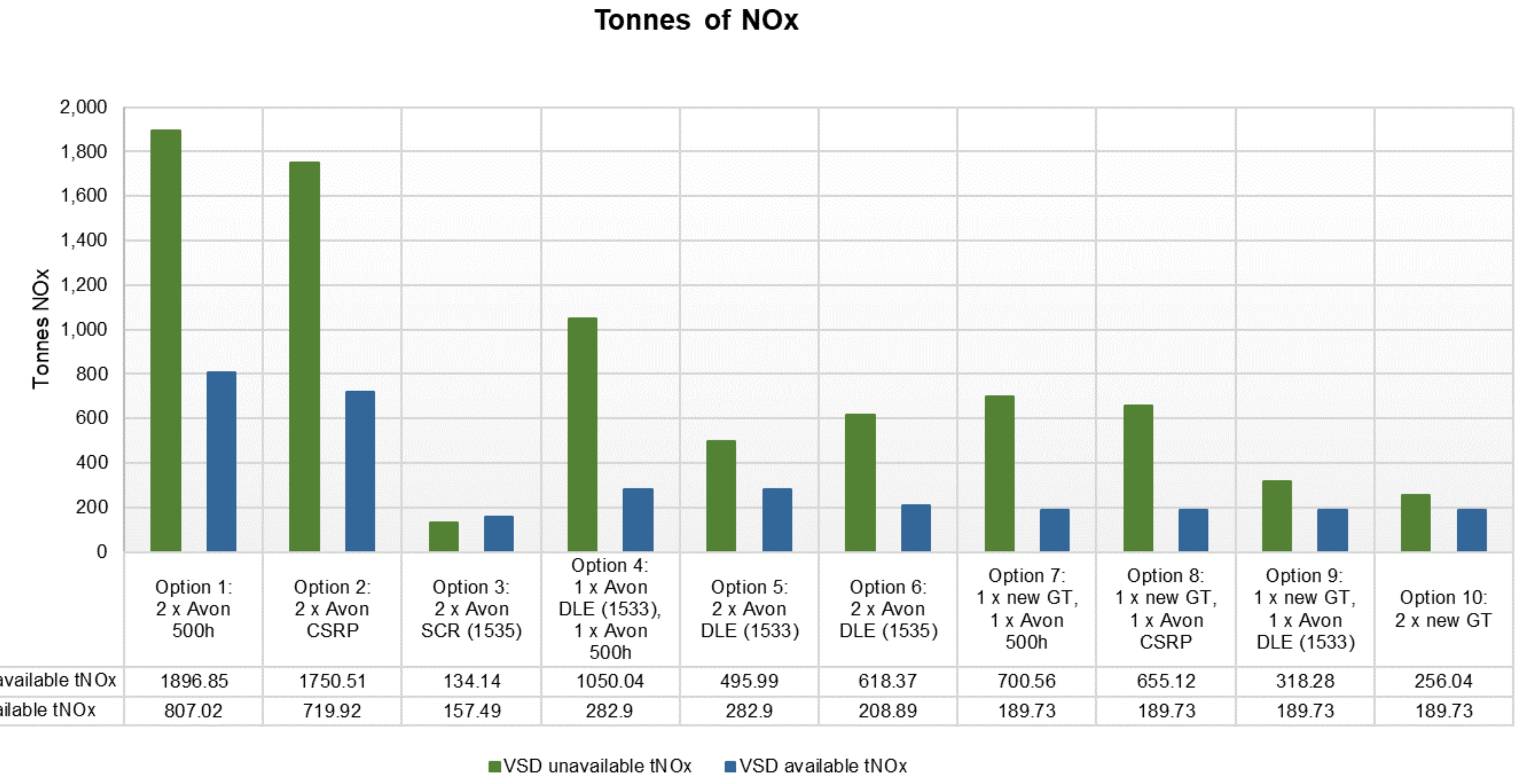


Mass emissions

The potential for the candidate BAT options to reduce total mass emissions is presented in the following charts. The charts illustrate total tonnes emitted over the 20-year period of the BAT model. The new GT options and SCR option provide the greatest potential to reduce emissions compared with the current arrangements on site.

It should be noted that emission calculations for the Avon DLE options assume certain emissions factors provided by OEMs developing separate techniques for the 1533 and 1535 engine models, which are not proven at engine scale and may be subject to future change.

Figure 9 tNOx emissions



	Option 1: 2 x Avon 500h	Option 2: 2 x Avon CSRP	Option 3: 2 x Avon SCR (1535)	Option 4: 1 x Avon DLE (1533), 1 x Avon 500h	Option 5: 2 x Avon DLE (1533)	Option 6: 2 x Avon DLE (1535)	Option 7: 1 x new GT, 1 x Avon 500h	Option 8: 1 x new GT, 1 x Avon CSRP	Option 9: 1 x new GT, 1 x Avon DLE (1533)	Option 10: 2 x new GT
VSD unavailable tNOx	1896.85	1750.51	134.14	1050.04	495.99	618.37	700.56	655.12	318.28	256.04
VSD available tNOx	807.02	719.92	157.49	282.9	282.9	208.89	189.73	189.73	189.73	189.73

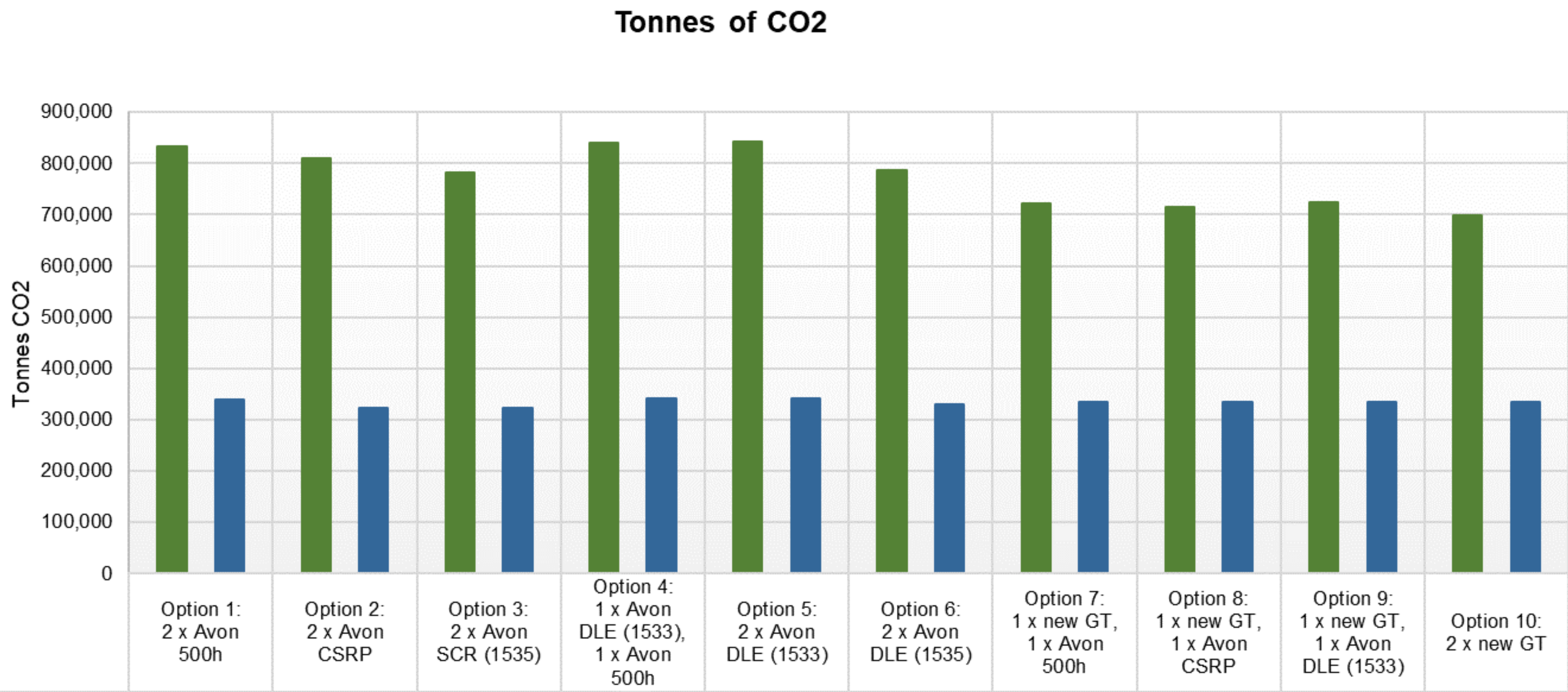
The chart illustrates that total NOx emissions are higher when the VSD is unavailable (with the exception of the SCR option) compared to when the VSD is operating. This is due to grid electricity emission factors for CO_2 and NOx, which includes renewable and nuclear sources which do not result in NOx emissions. The options that retain an Avon on 500h and the Avon CSRP options have the highest NOx levels as they have no abatement technique and perform poorly in terms of emissions.

When the VSD is available, Option 5 (2 x Avon DLE 1533) has higher total NOx emissions compared with Option 6 (2 x Avon DLE 1535), however, when the VSD is unavailable this is reversed. This is due the larger engine (Avon 1535) producing higher NOx emissions (g/s) when it is turned down, operating at PDS points that would usually be met by the VSD operating on its own.

The Avon SCR option produces least NOx in the assessment followed by the two new GTs. The Avon DLE options perform slightly less well than SCR or new GT options, but still represent a significant improvement in NOx performance compared to an unabated Avon.

The realised emissions will depend on the likely percentage availability of the VSD.

Figure 10 tCO2 emissions



	Option 1: 2 x Avon 500h	Option 2: 2 x Avon CSRP	Option 3: 2 x Avon SCR (1535)	Option 4: 1 x Avon DLE (1533), 1 x Avon 500h	Option 5: 2 x Avon DLE (1533)	Option 6: 2 x Avon DLE (1535)	Option 7: 1 x new GT, 1 x Avon 500h	Option 8: 1 x new GT, 1 x Avon CSRP	Option 9: 1 x new GT, 1 x Avon DLE (1533)	Option 10: 2 x new GT
VSD unavailable tCO2	834065.71	809224.17	781952.9	839297.7	842406.37	785710.49	722094.29	714406.69	724158.19	699262.45
VSD available tCO2	338975.94	323659.8	323106.34	341517.81	341517.81	328972.07	334783.35	334783.35	334783.35	334783.35

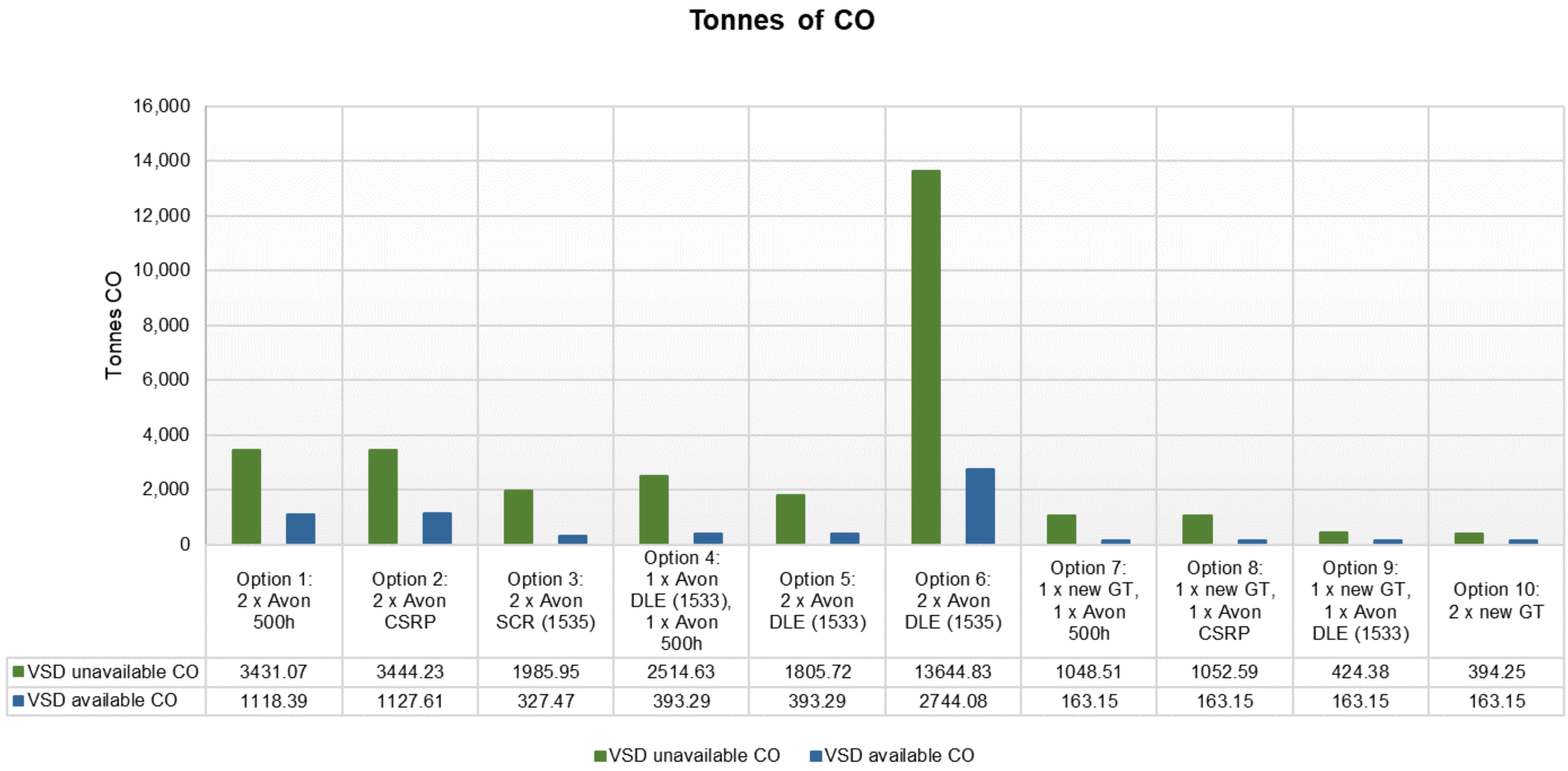
For the VSD available case, the Avon SCR 1535 and Avon CSRP produce marginally lower CO_2 emissions in this BAT assessment, compared to other options. For CSRP this is partly as a result of reduced compression capability and the combustion of less fuel gas on the study site; the compression shortfall (with associated emissions) would be made up elsewhere; this cannot be readily accounted for in the BAT model.

When the VSD is available, the BAT assessment indicates that total emissions are higher for options using an Avon DLE 1533 compared to those using an Avon 1535. This is as a result of the Avon 1533 being slightly less fuel efficient than the Avon 1535. The DLE technique also has the effect of slightly reducing efficiency.

Options using a new GT with the VSD can meet all compression requirements and have equal emission levels. Consequently, although newer GTs are more efficient, the increased shaft power results in higher overall fuel consumption compared with an existing Avon 1533 running with a VSD. Note that the Avon 1533 working with the VSD does not fully meet all PDS points. Overall, there is very little material difference between CO_2 levels when comparing the VSD available cases.

CO_2 emissions are at least twice as high for options when the VSD is not operating, as a result of increased levels of fuel gas consumption. Indirect CO_2 emissions are included within the BAT model calculations for electricity usage based on an emissions factor; indirect emissions are lower than direct emissions due to the grid mix (which includes a significant contribution from renewable sources).

Figure 11 tCO emissions



	Option 1: 2 x Avon 500h	Option 2: 2 x Avon CSRP	Option 3: 2 x Avon SCR (1535)	Option 4: 1 x Avon DLE (1533), 1 x Avon 500h	Option 5: 2 x Avon DLE (1533)	Option 6: 2 x Avon DLE (1535)	Option 7: 1 x new GT, 1 x Avon 500h	Option 8: 1 x new GT, 1 x Avon CSRP	Option 9: 1 x new GT, 1 x Avon DLE (1533)	Option 10: 2 x new GT
VSD unavailable CO	3431.07	3444.23	1985.95	2514.63	1805.72	13644.83	1048.51	1052.59	424.38	394.25
VSD available CO	1118.39	1127.61	327.47	393.29	393.29	2744.08	163.15	163.15	163.15	163.15

The Avon 1535 DLE has the lowest performance level in terms of CO mass emissions. Currently available test results are resulting in an increase in CO emissions for the Avon DLE 1535 option. Emissions as modelled use actual performance data for a 1535 engine in the National Grid fleet together with OEM DLE technique emission factors. This results in total CO emissions for the 20-year period being higher than for options using an Avon 1533. The Avon SCR 1535 includes a catalyst that reduces CO, hence emissions are lower.

The Avon 500h and Avon CSRP options have the second highest emissions. CO emissions are lowest for options with a new GT, reflecting the excellent combustion controls associated with modern GTs.

Indirect CO emissions associated with electricity supply from the grid for the VSD are not considered in the BAT model; this is a conscious exclusion from the BAT model process on the basis that CO emissions should be minimal from efficiently generated electricity and absent from renewable sources.

Summary of findings

Key findings

- For future gas compressor running scenarios, where the VSD is operating as the lead unit, a second compressor unit is required to meet all or part of the compression requirements of Case 3.
- Options retaining an Avon on 500 hours or with CSRP have lower technical/environmental scores than options utilising Avon DLE/SCR retrofit technology or investment in a new GT. This is due to their reduced versatility as a result of limited running hours or a restricted compressor envelope, no future proofing against potential tightening of emissions legislation and no NOx emissions abatement. Options 1 and 2 do not represent BAT, and wider network constraints would occur.
- The options that include an Avon DLE have similar technical/environmental scores, with the Avon 1535 option having greater versatility (albeit at a higher cost due to the wider range of upgrades needed compared to an Avon 1533 DLE retrofit). At the time of writing, Avon 1533 retrofit solutions are undergoing bench scale testing, whereas 1535 DLE retrofit solutions have not yet progressed this far.
- When the VSD is not operational, Options 3 (2 x SCR), 5 (2 x Avon DLE 1533) and 6 (2 x Avon DLE 1535) could all potentially represent a BAT solution since their costs and performance are not materially different.
- However, the retrofit DLE technique is not proven on the network; this limitation is noted below.
- Option 3 (2 x SCR) is a proven technique in the gas transmission sector (but not yet on the UK NTS), however it is considered likely to be more costly than the Avon DLE technique, and site footprint requirements are likely to make the construction of SCR on both Avons unfeasible at Wormington.
- Options that include a new GT have the highest overall cost. However, these options do provide significant technical/environmental gain over Avon-based solutions.
- When the VSD is unavailable, options that include a new GT but retain an Avon on 500h or fitted with CSRP, have a lower technical/environmental performance compared with an Avon DLE or a second new GT.
- When the VSD is unavailable and constraint costs are included, Option 10 has the lowest overall cost and highest technical/environmental score in the BAT assessment..
- The BAT assessment indicates that when constraint costs are included, Option 10 (2 x new GT) and Option 9 (1 x GT and 1 x Avon DLE 1533) could potentially represent BAT; Option 10 by the greatest margin when looking at VSD unavailable cases.
- The BAT assessment process described herein should only be considered as a decision support process, not a decision making process. Full justification for option selection, considering BAT and CBA outputs is described in the Formal Option Selection Report (FOSR).
- A number of assumptions and estimates have been made in the underlying data input points, these should be reviewed in making final decisions based on these findings.

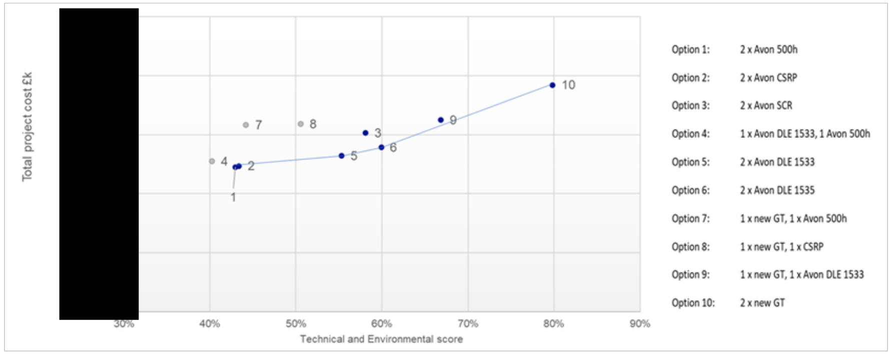
Limitations and assumptions

- Analysis of the compression capability of the units comprising the BAT options identified that when the VSD is operating as the lead unit, only options that include a new GT can meet all the PDS cases of Case 3. When the VSD is not operating, only the 2 x new GT option can meet all the PDS points of Case 3. This BAT assessment was undertaken using thermal power input data and emissions data assuming the duty of the units was optimised. When power requirements are in excess of the duty, this was recorded as potential buyback and quantified in the CBA constraint costs. The power and emissions associated with the shortfalls are not included in the BAT.
- Although the retrofit Avon DLE options were assessed to provide technical advantages, this technique is not fully proven in site-based operations. This risk is most marked for the Avon DLE 1535 options, where testing on a single combustor can only exist. Site-based trials are proposed for the Avon DLE 1533 technique in late 2022. SCR is a proven technique, however considered unsuitable for Wormington due to construction footprint constraints.
- A key difference between the CBA and the BAT assessment is that the BAT assessment takes into consideration NOx emissions. This difference is most apparent when comparing the results for options including CSRP. As a technique, CSRP is considered to be an option that will enable NOx emissions to be maintained below 150mg/Nm^3. It is currently expected that the environmental regulators will view this technique as suitable to gain compliance with the MCPD Directive emission limits, however no definitive response from the regulators is currently available. CSRP however does not:
    - Reduce overall NOx mass emissions.
    - Provide any level of future proofing should emissions limits tighten.
- For these reasons, CSRP solutions may be viewed by environmental regulators as being more suited to back-up or low utilisation applications.
- These issues result in options with CSRP achieving lower technical/environmental scores in the BAT assessment compared with Avon retrofit emissions abatement solutions/new GTs. Since these factors are not evaluated in the CBA, CSRP options perform relatively better in the CBA compared with the BAT assessment.

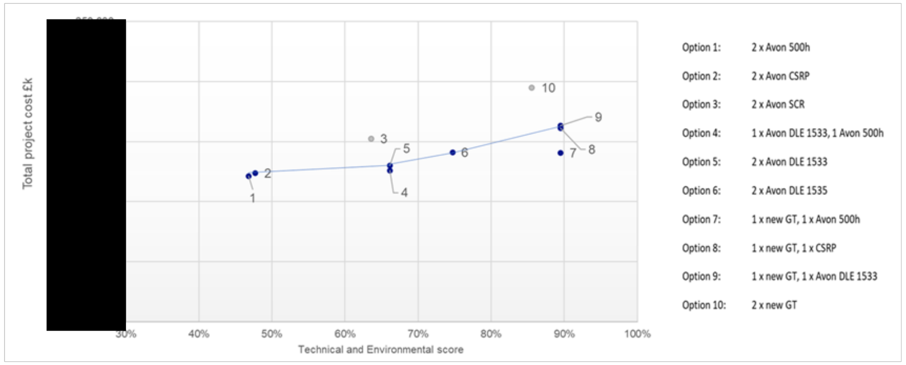
A summary of the results narrative is presented overleaf in Figure 12.

Figure 12 Summary of the results narrative

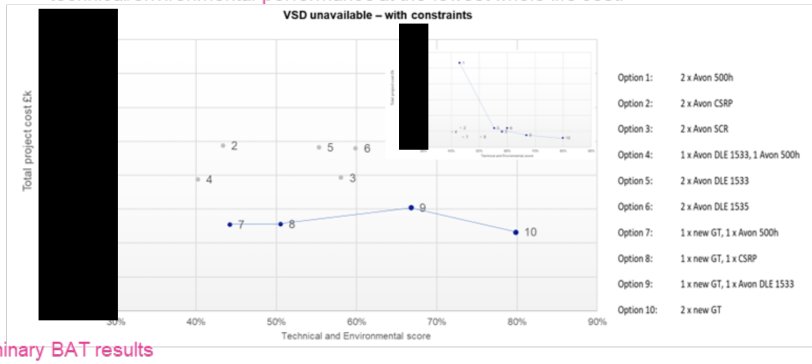
1 Wormington 2022 BAT was on 'Case 3 MCPD plus PARCA – WGP reinforcements in case 2 but limit lead compression capability to 30MW'. Preliminary review of BAT when lead 'VSD unavailable' shows options that retain a non-mitigated Avon scoring less well compared with options with 2 mitigated Avons or 2 new GTs.



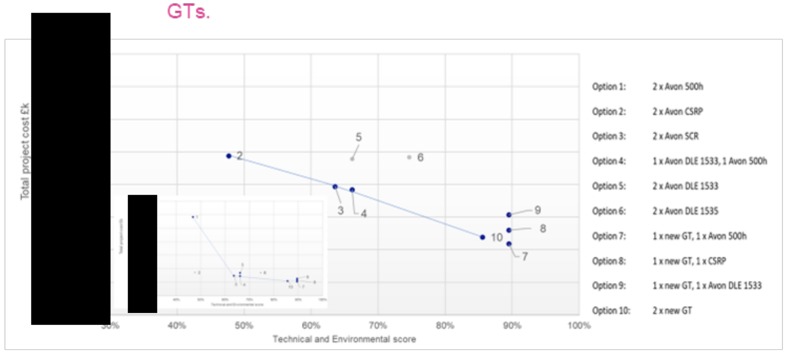
2 A 'VSD available' scenario is explored next, which presents a different indicative BAT outcome, with single mitigated Avon/single GT options scoring better.



3 The BAT assessment usually only considers site specific factors. Given that Wormington is a strategically critical site, a sensitivity is run included constraint costs derived from the CBA, to take account of wider network costs. These costs have a material influence on the BAT results with VSD unavailable. Option 10 (2 x new GTs) has the highest technical/environmental performance at the lowest whole life cost.



4 When the VSD is available, options that include a single new GT form a cluster of potential BAT options, together with 2 x new GTs.



STOP Preliminary BAT results