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CONSTRUCTION & OPERATIONAL STAGE ASSESSMENT OF AIR QUALITY & CLIMATE IMPACTS ASSOCIATED WITH THE PROPOSED K2 DATA CENTRE ON KINGSWOOD DRIVE AND KINGSWOOD ROAD, WITHIN THE CITYWEST BUSINESS CAMPUS, NAAS ROAD, DUBLIN 24

Technical Report Prepared For

K2 Strategic Infrastructure Ireland Ltd.

Technical Report Prepared By

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EXECUTIVE SUMMARY

This report presents the assessment of air quality and climate impacts as a result of the proposed data centre during the construction and operational stages. An assessment of the likely dust related impacts as a result of construction activities was undertaken and used to inform a series of mitigation measures. Air dispersion modelling of operational stage emissions was carried out using the United States Environmental Protection Agency's regulated model AERMOD. The modelling of air emissions from the site was carried out to assess concentrations of nitrogen dioxide (NO_2) at a variety of locations beyond the site boundary. The modelling was undertaken to assess the impact to ambient air quality from the testing of the standby generators and the infrequent emergency operation of the standby generators.

The proposed data centre (subject to amendments under the current application) will have 5 no. standby diesel generators which will each have 2 no. associated stacks. Each of the 10 no. stacks will have a minimum height of 15m above ground level.

USEPA Guidance suggests that for emergency operations, an average hourly emission rate should be used rather than the maximum hourly rate[22]. As a result, the maximum hourly emission rates from the standby generators were reduced by $\frac{100}{8760}$ and the generators were modelled over a period of one full year. In reality, the standby generators are likely to run for only 24 - 48 hours per year.

A second methodology has been published by the UK Environment Agency (UK EA)[21] and is based on considering the statistical likelihood of an exceedance of the NO_2 hourly limit value (18 exceedances are allowable per year before the air standard is deemed to have been exceeded). The assessment assumes a hypergeometric distribution to assess the likelihood of exceedance hours coinciding with the operational hours of the standby generators. The guidance also states that there should be no running time restrictions on standby generators when providing power on site during an emergency. Both the methodology advised in USEPA guidance as well as the approach described in the UK EA guidance have been applied in this study to ensure a robust assessment of predicted air quality impacts from the standby generators.

Assessment Summary

Construction Stage

There are no sensitive receptors within 200 m of the site boundary. The air quality impacts during the construction phase are deemed to be ***short-term*** and ***imperceptible.***

Operational Stage

The results indicate that ambient ground level concentrations are below the relevant air quality standards for NO_2 for all scenarios modelled. Emissions associated with the 5 no. standby generators lead to an ambient NO_2 concentration that is 65% of the ambient 1-hour limit value (measured as a 99.8^{th} percentile) and 56% of the ambient annual mean limit value at the worst case off-site receptor for the worst case year.

The UKEA assessment methodology determined that the standby generators could operate for 2560 hours before there is a likelihood of an exceedance of the ambient air quality standard (at a 98^{th} percentile confidence level). However, the UK guidance recommends that there should be no running time restrictions placed on standby generators which provide power on site only during an emergency power outage.

In summary, impacts on ambient air quality associated with the standby generators at the proposed development site will be in compliance with the ambient air quality standards which are based on the protection of the environment and human health.

The climate assessment determined that based on the proposed development consuming a maximum of 10 MW of electricity, it will indirectly generate 25,912 tonnes of CO_2eq per year. However, electricity providers form part of the EU-wide Emission Trading Scheme (ETS) and thus greenhouse gas emission from these electricity generators are not included when determining compliance with the targeted 42% reduction in the non-ETS sector. Thus, emissions from electricity generators will not affect the EU 2030 target of a 42% reduction in non-Emission Trading Scheme (non-ETS) greenhouse gas emissions by 2030. Consequently, the proposed development will have no impact on whether Ireland meets the targets set for 2030. Given that the use of electricity to power the facility will achieve net zero by 2050 and the commitment to offset all interim fossil fuel derived GHG emissions by the purchase of renewable electricity from SSE Airtricity the predicted impact to climate is deemed to be indirect, long-term, negative and slight.

No significant impacts to either air quality or climate are predicted as a result of the proposed development.

CONTENTS

1.0 INTRODUCTION

This report presents the assessment of air quality and climate impacts as a result of the proposed K2 Data Centre (which the current application provides for amendments to), Kingswood Drive and Kingswood Road, within the Citywest Business Campus, Naas Road, Dublin 24, during the construction and operational stages. An assessment of the likely dust related impacts as a result of construction activities was undertaken and used to inform a series of mitigation measures. Air dispersion modelling of operational stage emissions from 5 no. standby diesel generators was carried out using the United States Environmental Protection Agency's regulated model AERMOD. The modelling of air emissions from the site was carried out to assess concentrations of nitrogen dioxide (NO_2) at a variety of locations beyond the site boundary. The modelling was undertaken to assess the impact to ambient air quality from the testing of the standby generators and the infrequent emergency operation of the standby generators.

The site is located in Citywest Business Campus which is approximately 10km from Dublin city centre. Most of the land surrounding the site is occupied by industrial facilities including data centre, manufacturing and commercial uses (see Figure 1). The Roadstone Belgard Quarry is directly to the east of the site. In terms of sensitive residential receptors, there are a number of large residential estates located further to the south (see Figure 1).

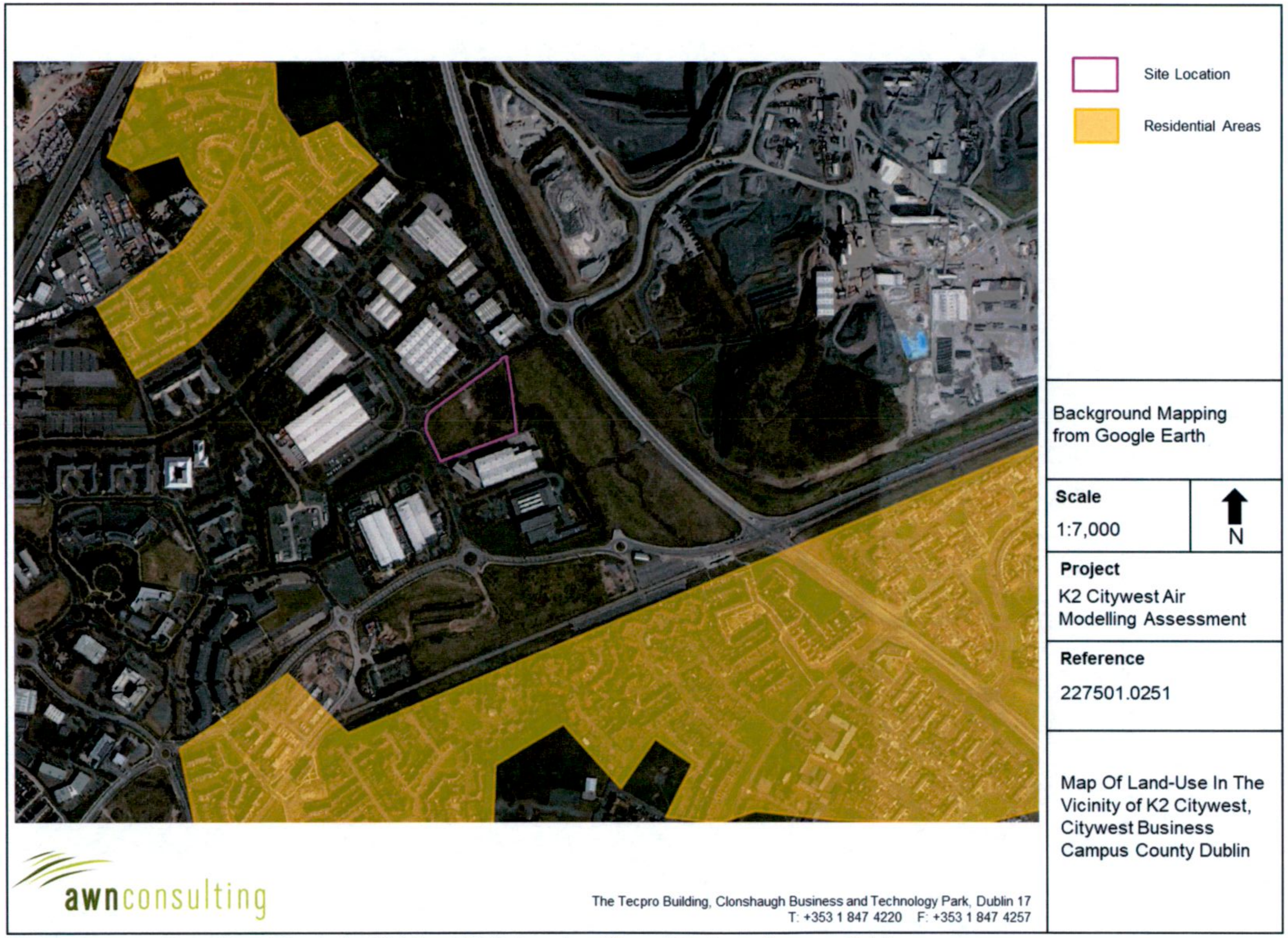

Figure 1 Map of Land-Use in the Vicinity of K2 Datacentre, Citywest Business Campus, Dublin

2.0 ASSESSMENT CRITERIA

2.1 Ambient Air Quality Standards

In order to reduce the risk to health from poor air quality, national and European statutory bodies have set limit values in ambient air for a range of air pollutants. These limit values or "Air Quality Standards" are health or environmental-based levels for which additional factors may be considered. The applicable standards in Ireland include the Air Quality Standards Regulations 2011, which incorporate EU Directive 2008/50/EC (see Table 1). The ambient air quality standards applicable for NO_2, PM_{10} and $PM_{2.5}$ are outlined in this Directive.

Air quality significance criteria are assessed on the basis of compliance with the appropriate standards or limit values. These standards have been used in the current assessment to determine the potential impact of NO_2, PM_{10} and $PM_{2.5}$ emissions from the facility on ambient air quality.

Pollutant	Regulation Note 1	Limit Type	Value
Nitrogen Dioxide (NO_2)	2008/50/EC	Hourly limit for protection of human health - not to be exceeded more than 18 times/year	200 µg/m^3
		Annual limit for protection of human health	40 µg/m^3
Particulate Matter (as PM_{10})	2008/50/EC	24-hour limit for protection of human health - not to be exceeded more than 35 times/year	50 µg/m^3 PM_{10}
		Annual limit for protection of human health	40 µg/m^3 PM_{10}
Particulate Matter (as $PM_{2.5}$)	2008/50/EC	Annual limit for protection of human health	25 µg/m^3 $PM_{2.5}$

Note 1 EU 2008/50/EC – Clean Air For Europe (CAFÉ) Directive replaces the previous Air Framework Directive (1996/30/EC) and daughter directives 1999/30/EC and 2000/69/EC

Table 1 Air Quality Standards 2011 (Based on Directive 2008/50/EC)

2.2 Dust Deposition Guidelines

The concern from a health perspective is focused on particles of dust which are less than 10 microns and the EU ambient air quality standards outlined in Section 2.1 have set ambient air quality limit values for PM_{10} and $PM_{2.5}$.

With regard to larger dust particles that can give rise to nuisance dust, there are no statutory guidelines regarding the maximum dust deposition levels that may be generated during the construction phase of a development in Ireland.

However, guidelines for dust deposition, the German TA-Luft standard for dust deposition (non-hazardous dust)(1) sets a maximum permissible immission level for dust deposition of 350 mg/(m^2*day) averaged over a one year period at any receptors outside the site boundary. Recommendations from the Department of the Environment, Heritage & Local Government(2) apply the Bergerhoff limit of 350 mg/(m^2*day) to the site boundary of quarries. This limit value can be implemented with regard to dust impacts from the construction of the proposed development.

3.0 ASSESSMENT METHODOLOGY

3.1 Construction Stage

The assessment of dust impacts from construction activities focused on identifying the existing baseline levels of PM_{10} and $PM_{2.5}$ in the region of the proposed development by an assessment of EPA monitoring data. Thereafter, the impact of the construction activities of the development on air quality was determined by a qualitative assessment of the nature and scale of dust generating construction activities associated with the development.

3.2 Operational Stage

Emissions from the facility have been modelled using the AERMOD dispersion model (Version 21112) which has been developed by the U.S. Environmental Protection Agency (USEPA)[3] and following guidance issued by the EPA[4]. The model is a steady-state Gaussian plume model used to assess pollutant concentrations associated with industrial sources and has replaced ISCST3[5] as the regulatory model by the USEPA for modelling emissions from industrial sources in both flat and rolling terrain[6-8]. The model has more advanced algorithms and gives better agreement with monitoring data in extensive validation studies[8-12]. An overview of the AERMOD dispersion model is outlined in Appendix I.

The air dispersion modelling input data consisted of information on the physical environment (including building dimensions and terrain features), design details from all emission points on-site and five years of appropriate hourly meteorological data. Using this input data the model predicted ambient ground level concentrations beyond the site boundary for each hour of the modelled meteorological years. The model post-processed the data to identify the location and maximum of the worst-case ground level concentration. This worst-case concentration was then added to the background concentration to give the worst-case predicted environmental concentration (PEC). The PEC was then compared with the relevant ambient air quality standard to assess the significance of the releases from the site.

Throughout this study a worst-case approach was taken. This will most likely lead to an over-estimation of the levels that will arise in practice. The worst-case assumptions are outlined below:

- Maximum predicted concentrations were reported in this study, even if no residential receptors were near the location of this maximum;
- Worst-case background concentrations were used in the assessment;
- The effects of building downwash, due to on-site buildings, has been included in the model;
- Testing of the standby generators was assumed to occur each week for each generator; in reality testing is more likely to occur once every two weeks.
- Emergency operations were assumed to occur for a maximum of 100 hours per year calculated according to USEPA methodology, in reality generators are likely to be used for emergency operation for 24 – 48 hours per year if at all.

3.2.1 Air Dispersion Modelling Methodology

The United States Environmental Protection Agency (USEPA) approved AERMOD dispersion model has been used to predict the ground level concentrations (GLC) of compounds emitted from the principal emission sources on-site.

The modelling incorporated the following features:

- Two receptor grids were created at which concentrations would be modelled. Receptors were mapped with sufficient resolution to ensure all localised "hot-spots" were identified without adding unduly to processing time. The receptor grids were based on Cartesian grids with the site at the centre. An outer grid measured 10 x 10 km with the site at the centre and with concentrations calculated at 250m intervals. A smaller denser grid measured 3 x 3 km with the site at the centre and concentrations calculated at 50m intervals. Boundary receptor locations were also placed along the boundary of the site, at 25m intervals, giving a total of 5,666 calculation points for the model.

- Discrete receptors were also added to the model to represent nearby residential receptors.

- All on-site buildings and significant process structures were mapped into the computer to create a three dimensional visualisation of the site and its emission points. Buildings and process structures can influence the passage of airflow over the emission stacks and draw plumes down towards the ground (termed building downwash). The stacks themselves can influence airflow in the same way as buildings by causing low pressure regions behind them (termed stack tip downwash). Both building and stack tip downwash were incorporated into the modelling.

- Detailed terrain has been mapped into the model using SRTM data with 30m resolution. The site is located in an area of complex terrain. All terrain features have been mapped in detail into the model using the terrain pre-processor AERMAP(13).

- Hourly-sequenced meteorological information has been used in the model. Meteorological data over a five year period (Casement Aerodrome 2017 – 2021) was used in the model (see Figure 2 and Appendix II).

- The source and emissions data, including stack dimensions, gas volumes and emission temperatures have been incorporated into the model.

3.2.2 *Terrain*

The AERMOD air dispersion model has a terrain pre-processor AERMAP(13) which was used to map the physical environment in detail over the receptor grid. The digital terrain input data used in the AERMAP pre-processor was obtained from SRTM. This data was run to obtain for each receptor point the terrain height and the terrain height scale. The terrain height scale is used in AERMOD to calculate the critical dividing streamline height, H_{crit}, for each receptor. The terrain height scale is derived from the Digital Elevation Model (DEM) files in AERMAP by computing the relief height of the DEM point relative to the height of the receptor and determining the slope. If the slope is less than 10%, the program goes to the next DEM point. If the slope is 10% or greater, the controlling hill height is updated if it is higher than the stored hill height.

In areas of complex terrain, AERMOD models the impact of terrain using the concept of the dividing streamline (H_c). As outlined in the AERMOD model formulation(3) a plume embedded in the flow below H_c tends to remain horizontal; it might go around the hill or impact on it. A plume above H_c will ride over the hill. Associated with this is a tendency for the plume to be depressed toward the terrain surface, for the flow to speed up, and for vertical turbulent intensities to increase.

AERMOD model formulation states that the model "captures the effect of flow above and below the dividing streamline by weighting the plume concentration associated with two possible extreme states of the boundary layer (horizontal plume and terrain-following). The relative weighting of the two states depends on: 1) the degree of atmospheric stability; 2) the wind speed; and 3) the plume height relative to terrain. In stable conditions, the horizontal plume "dominates" and is given greater weight while in neutral and unstable conditions, the plume traveling over the terrain is more heavily weighted"(4).

3.2.3 Meteorological Data

The selection of the appropriate meteorological data has followed the guidance issued by the USEPA(3). A primary requirement is that the data used should have a data capture of greater than 90% for all parameters. Casement Aerodrome meteorological station, which is located approximately 2 km northwest of the site, collects data in the correct format and has a data collection of greater than 90%. Long-term hourly observations at Casement Aerodrome meteorological station provide an indication of the prevailing wind conditions for the region (see Figure 2 and Appendix II)(14). Results indicate that the prevailing wind direction is westerly to south-westerly in direction over the period 2017 - 2021. The mean wind speed is approximately 5.5 m/s over the period 2017 - 2021. Calm conditions account for only a small fraction of the time in any one year peaking at 70 hours in 2018 (0.8% of the time).

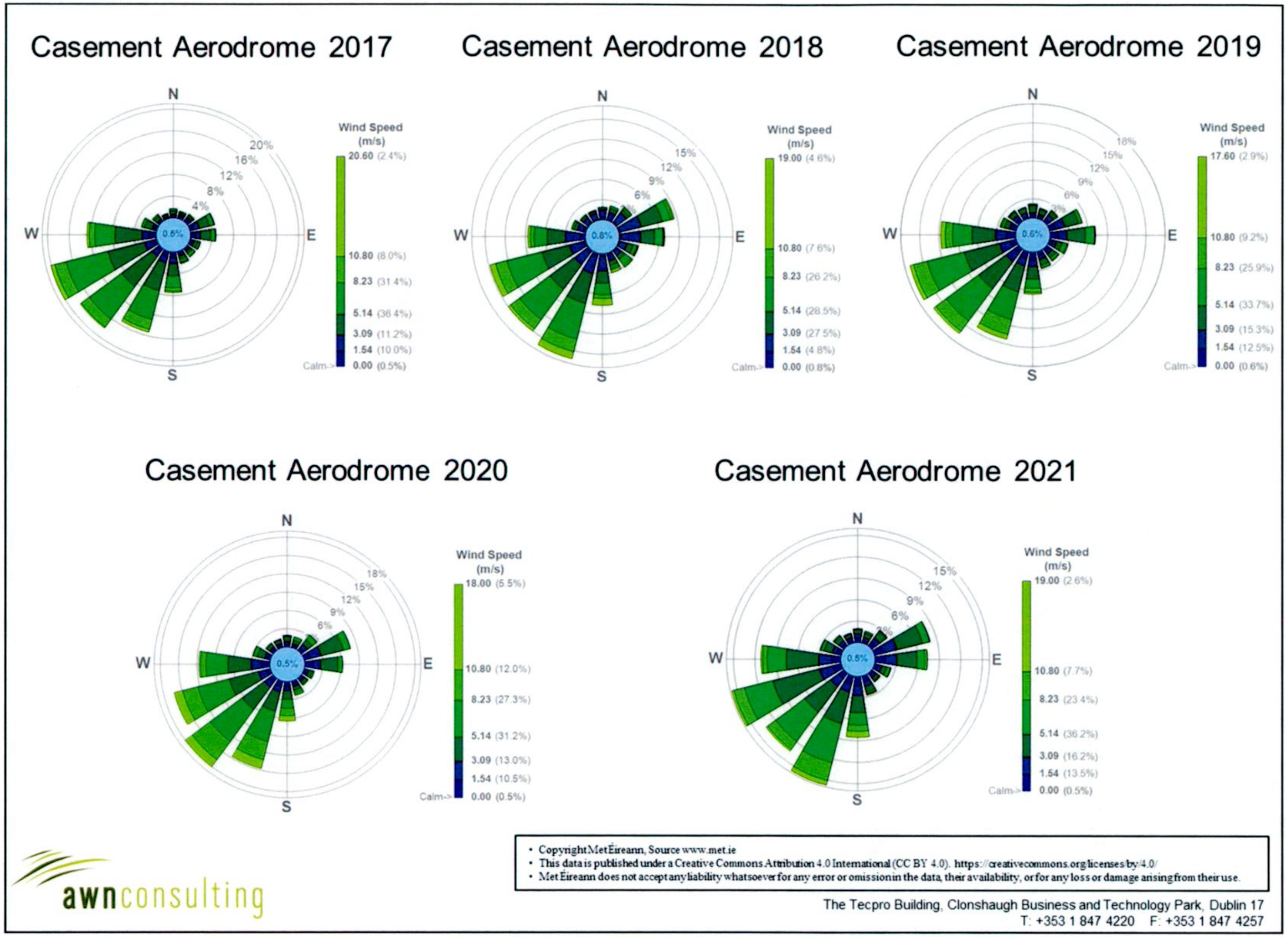

Figure 2 Casement Aerodrome Windrose 2017 – 2021

3.2.4 Geophysical Considerations

AERMOD simulates the dispersion process using planetary boundary layer (PBL) scaling theory[3]. PBL depth and the dispersion of pollutants within this layer are influenced by specific surface characteristics such as surface roughness, albedo and the availability of surface moisture. Surface roughness is a measure of the aerodynamic roughness of the surface and is related to the height of the roughness element. Albedo is a measure of the reflectivity of the surface whilst the Bowen ratio is a measure of the availability of surface moisture.

AERMOD incorporates a meteorological pre-processor AERMET[15] to enable the calculation of the appropriate parameters. The AERMET meteorological preprocessor requires the input of surface characteristics, including surface roughness (z_0), Bowen Ratio and albedo by sector and season, as well as hourly observations of wind speed, wind direction, cloud cover, and temperature. The values of albedo, Bowen Ratio and surface roughness depend on land-use type (e.g., urban, cultivated land etc) and vary with seasons and wind direction. The assessment of appropriate land-use type was carried out to a distance of 10km from the meteorological station for Bowen Ratio and albedo and to a distance of 1km for surface roughness in line with USEPA recommendations[15,16] as outlined in Appendix II.

In relation to AERMOD, detailed guidance for calculating the relevant surface parameters has been published[17]. The most pertinent features are:

- The surface characteristics should be those of the meteorological site (Casement Aerodrome) rather than the installation;
- Surface roughness should use a default 1km radius upwind of the meteorological tower and should be based on an inverse-distance weighted geometric mean. If land use varies around the site, the land use should be sub-divided by sectors with a minimum sector size of 30°;
- Bowen ratio and albedo should be based on a 10km grid. The Bowen ratio should be based on an un-weighted geometric mean. The albedo should be based on a simple un-weighted arithmetic mean.

AERMOD has an associated pre-processor, AERSURFACE[18] which has representative values for these parameters depending on land use type. The AERSURFACE pre-processor currently only accepts NLCD92 land use data which covers the USA. Thus, manual input of surface parameters is necessary when modelling in Ireland. Ordnance survey discovery maps (1:50,000) and digital maps such as those provided by the EPA, National Parks and Wildlife Service (NPWS) and Google Earth® are useful in determining the relevant land use in the region of the meteorological station. The Alaska Department of Environmental Conservation has issued a guidance note for the manual calculation of geometric mean for surface roughness and Bowen ratio for use in AERMET[17]. This approach has been applied to the current site with full details provided in Appendix II.

3.2.5 Building Downwash

When modelling emissions from an industrial installation, stacks which are relatively short can be subjected to additional turbulence due to the presence of nearby buildings. Buildings are considered nearby if they are within five times the lesser of the building height or maximum projected building width (but not greater than 800m).

The USEPA has defined the "Good Engineering Practice" (GEP) stack height as the building height plus 1.5 times the lesser of the building height or maximum projected building width. It is generally considered unlikely that building downwash will occur when stacks are at or greater than GEP[18].

When stacks are less than this height, building downwash will tend to occur. As the wind approaches a building it is forced upwards and around the building leading to the formation of turbulent eddies. In the lee of the building these eddies will lead to downward mixing (reduced plume centreline and reduced plume rise) and the creation of a cavity zone (near wake) where re-circulation of the air can occur. Plumes released from short stacks may be entrained in this airflow leading to higher ground level concentrations than in the absence of the building.

The Plume Rise Model Enhancements (PRIME)[11,12] plume rise and building downwash algorithms, which calculates the impact of buildings on plume rise and dispersion, have been incorporated into AERMOD. The building input processor BPIP-PRIME produces the parameters which are required in order to run PRIME. The model takes into account the position of each stack relative to each relevant building and the projected shape of each building for 36 wind directions (at 10° intervals). The model determines the change in plume centreline location with downwind distance based on the slope of the mean streamlines and coupled to a numerical plume rise model[11].

Given that the proposed stacks are less than 2.5 times the lesser of the building height or maximum projected building width, building downwash will need to be taken into account and the PRIME algorithm run prior to modelling with AERMOD. The dominant building for each relevant stack will vary as a function of wind direction and relative building heights.

3.2.6 Climate

The standby diesel generators modelled for the purpose of this assessment will only be used in the event of a power failure at the site. In reality and based on recent experience over the past number of years, generators are rarely used other than during testing and maintenance described in Section 5.0. During normal operations at the facility, the electricity will be supplied from the national grid so there will be no direct emissions of CO_2 from the site.

The impact of the operational phase of the proposed development on climate was determined by an assessment of the indirect CO_2 emissions associated with the electricity supplied from the national grid. The details and results of the assessment are provided in Section 6.2.4.

4.0 BACKGROUND CONCENTRATIONS OF POLLUTANTS

Air quality monitoring programs have been undertaken in recent years by the EPA and Local Authorities[19,20]. The most recent annual report on air quality "Air Quality Monitoring Annual Report 2020"[20], details the range and scope of monitoring undertaken throughout Ireland. As part of the implementation of the Framework Directive on Air Quality (1996/62/EC), four air quality zones have been defined in Ireland for air quality management and assessment purposes[19]. Dublin is defined as Zone A and Cork as Zone B. Zone C is composed of 23 towns with a population of greater than 15,000. The remainder of the country, which represents rural Ireland but also includes all towns with a population of less than 15,000 is defined as Zone D. In terms of air monitoring, Citywest Business Campus is categorised as Zone A[19].

In 2020 the EPA reported (EPA, 2021) that Ireland was compliant with EU legal air quality limits at all locations, however this was largely due to the reduction in traffic due to Covid-19 restrictions. The EPA *Air Quality in Ireland 2020* report details the effect that the Covid-19 restrictions had on air monitoring stations, which included reductions of up to 50% at some monitoring stations which have traffic as a dominant source. The report also notes that CSO figures show that while traffic volumes are still slightly below 2019 levels, they have significantly increased since 2020 levels. 2020 concentrations are therefore predicted to be an exceptional year and not consistent with long-term trends. For this reason, they have not been included in the baseline section and previous long-term data has been used to determine baseline levels of pollutants in the vicinity of the proposed development.

4.1 NO_2

With regard to NO_2, continuous monitoring data from the EPA(20), at suburban Zone A background locations in Rathmines, Dun Laoghaire, Swords and Ballyfermot show that current levels of NO_2 are below both the annual and 1-hour limit values, with annual average levels ranging from 13 - 22 $\mu g/m^3$ over the period 2015 - 2019 (see Table 2). Sufficient data is available for the station in Swords to observe long-term trends since 2015(20) with annual average results ranging from 13 – 16 $\mu g/m^3$, with an average of 14.5 $\mu g/m^3$. Based on these results, an estimate of the current background NO_2 concentration in the region of the proposed development is 17 $\mu g/m^3$.

The Plume Volume Molar Ratio Method (PVMRM) was used to model NO_2 concentrations. The PVMRM is currently a non-regulatory option in AERMOD which assumes that the amount of NO converted to NO_2 is proportional to the ambient ozone concentration(25,26). The PVMRM uses both plume size and O_3 concentration to derive the amount of O_3 available for the reaction between NO and O_3. NO_X moles are determined by emission rate and travel time through the plume segment. The concentration is usually limited by the amount of ambient O_3 that is entrained in the plume. Thus, the ratio of the moles of O_3 to the moles of NO_X gives the ratio of NO_2/NO_X that is formed after the NO_X leaves the stack. In addition, it has been assumed that 10% of the NO_X in the stack gas is already in the form of NO_2 before the gas leaves the stack (in reality the levels are usually closer to 5%(25,26). The model has also assumed a final equilibrium ratio for NO_2/NO_X of 0.90 which again is pessimistic and more likely to be in the range 0.7 – 0.8 (25,26). The equation used in the algorithm to derive the ratio of NO_2/NO_X is:

$$NO_2/NO_X = (\text{moles } O_3/ \text{ moles } NO_X) + 0.10$$

A background ozone concentration of 54 $\mu g/m^3$ was used in the modelling assessment, based on a review of worst case background ozone data for Zone A sites.

In relation to the annual average background, the ambient background concentration was added directly to the process concentration with the short-term peaks assumed to have an ambient background concentration of twice the annual mean background concentration.

Station	Averaging Period	Year				
		2015	2016	2017	2018	2019
Rathmines	Annual Mean NO_2 (µg/m^3)	18	20	17	20	22
	99.8th%ile 1-hr NO_2 (µg/m^3)	105	88	86	87	-
Ballyfermot	Annual Mean NO_2 (µg/m^3)	16	17	17	17	20
	99.8th%ile 1-hr NO_2 (µg/m^3)	127	90	112	101	-
Dun Laoghaire	Annual Mean NO_2 (µg/m^3)	16	19	17	19	15
	99.8th%ile 1-hr NO_2 (µg/m^3)	91	105	101	91	-
Swords	Annual Mean NO_2 (µg/m^3)	13	16	14	16	15
	99.8th%ile 1-hr NO_2 (µg/m^3)	93	96	79	85	-

Table 2 Annual Mean and 99.8th Percentile 1-Hour NO_2 Concentrations In Zone A Locations (µg/m^3)

4.2 PM_{10}

Continuous PM_{10} monitoring carried out at the suburban background locations of Ballyfermot, Dún Laoghaire, Rathmines and Tallaght showed annual mean concentrations ranging from 11 – 15 µg/m^3 in 2019 (see Table 3), with at most 9 exceedances (in Rathmines) of the daily limit value of 50 µg/m^3 (35 exceedances are permitted per year)[20]. Sufficient data is available for all stations to observe trends over the period 2015 – 2019. Average annual mean PM_{10} concentrations ranged from 9 - 16 µg/m^3 over the period of 2015 – 2019, suggesting an upper average concentration of no more than 12.9 µg/m^3. PM_{10} results from the urban background location in the Phoenix Park show similarly low levels over the period of 2015 – 2019 with concentrations ranging from 9 – 12 µg/m^3. Based on these results, a conservative estimate of the background PM_{10} concentration in the region of the proposed development is 15 µg/m^3.

Station	Averaging Period	Year				
		2015	2016	2017	2018	2019
Ballyfermot	Annual Mean PM_{10} (µg/m^3)	12	11	12	16	14
	24-hr Mean > 50 µg/m^3 (days)	3	0	1	0	7
Dun Laoghaire	Annual Mean PM_{10} (µg/m^3)	13	13	12	13	12
	24-hr Mean > 50 µg/m^3 (days)	3	0	2	0	2
Phoenix Park	Annual Mean PM_{10} (µg/m^3)	14	14	12	15	12
	24-hr Mean > 50 µg/m^3 (days)	4	0	2	1	3
Rathmines	Annual Mean PM_{10} (µg/m^3)	15	15	13	15	15
	24-hr Mean > 50 µg/m^3 (days)	5	3	5	2	9
Tallaght	Annual Mean PM_{10} (µg/m^3)	12	11	9	11	11
	24-hr Mean > 50 µg/m^3 (days)	2	0	1	0	2

Table 4 Background PM_{10} Concentrations In Zone A Locations (µg/m^3)

4.3 $PM_{2.5}$

Continuous $PM_{2.5}$ monitoring carried out at the Zone A location of Rathmines showed an average concentrations ranging from 9 – 10 µg/m^3 over the 2015 – 2019 period, with a $PM_{2.5}/PM_{10}$ ratio ranging from 0.60 – 0.68. Based on this information, a conservative ratio of 0.7 was used to generate a background $PM_{2.5}$ concentration in the region of the development of 10.5 µg/m^3.

5.0 PROCESS EMISSIONS

The proposed data centre will have 5 no. standby diesel generators which will each have 2 no. associated stacks. There will be a total of 10 no. generator stacks on site which will be built to a minimum height of 15m above ground level to provide for adequate dispersion of pollutants.

Modelling for NO_2 was undertaken in detail. In relation to CO, PM_{10} and $PM_{2.5}$ no detailed modelling was undertaken. Emissions of these pollutants are significantly lower than the NO_X emissions from the generators relative to their ambient air quality standards and thus ensuring compliance with the NO_2 ambient limit value will ensure compliance for all other pollutants. For example, the emission of CO from the generators is at least twenty times lower than NO_X whilst the CO ambient air quality standard is 10,000 $\mu g/m^3$ compared to the 1-hour NO_2 standard of 200 $\mu g/m^3$. Similarly, levels of $PM_{10}/PM_{2.5}$ emitted from the generators will be significantly lower than NO_X emissions whilst the ambient air quality standards are comparable.

The scenarios modelled for this assessment include emergency operation of the generators for 100 hours per year calculated according to USEPA protocol. Emergency operations have been overestimated as it is unlikely that the generators would be used for emergency operations for more than 24 – 48 hours per year. A testing regime has also been included in the model:

- Testing of each generator on an individual basis once per week for 1 hour at 100% load. This is an over-estimation of actual operating conditions as the generators are likely to be only tested once every two weeks.
- All testing was assumed to occur from 9am to 6pm, Monday to Friday only.

USEPA Guidance suggests that for emergency operations, an average hourly emission rate should be used rather than the maximum hourly rate[21]. As a result, the maximum hourly emission rates from the emergency generators were reduced by $\frac{100}{8760}$ and the generators were modelled over a period of one full year. As stated above, the emergency generators are likely to run for only 24 - 48 hours per year; however it is not advisable to assume less than 100 hours per year using the USEPA method as this would not be a sufficiently conservative approach.

Stack Reference	Height Above Ground Level (m)	Exit Diameter (m)	Temp (K)	Max Volume Flow at 15% O_2 (Nm^3/hr)	Exit Velocity (m/sec actual)	NO_2	
						Concentration at 15% O_2 (mg/Nm^3)	Mass Emission (g/s)
K2 Citywest Proposed Standby Diesel Generators (Emergency Operations) Note 1	15	0.46	749.15	12,594 Note 2	33.5	1715 Note 2	4.5 Note 3 / 0.051 Note 4
K2 Citywest Proposed Standby Diesel Generators (Testing) Note 1	15	0.46	749.15	12,594 Note 2	33.5	1715 Note 2	4.5 Note 5

Note 1 For the purposes of this assessment normalised conditions are 273K, 101.3 kPa, dry gas, 15% O_2.
Note 2 Volume flow rate and emission concentration divided by 2 as there are 2 no. stacks per genset.
Note 3 Maximum emission rates used to model the hypergeometric distribution at the 98th%ile confidence level and weekly scheduled testing.
Note 4 Reduced emission rates based on USEPA protocol used to model emissions during emergency operation of generators based on 100 hours of operation.
Note 5 Maximum emission rates used to model scheduled emissions including testing.

Table 4 K2 Datacentre Standby Diesel Generator Emission Details

A second methodology has been published by the UK Environment Agency. The consultation document is entitled "Diesel Generator Short-Term NO_2 Impact Assessment"[(22)]. The methodology is based on considering the statistical likelihood of an exceedance of the NO_2 hourly limit value (18 exceedances are allowable per year before the air standard is deemed to have been exceeded). The assessment assumes a hypergeometric distribution to assess the likelihood of exceedance hours coinciding with the emergency operational hours of the standby generators. The cumulative hypergeometric distribution of 19 and more hours per year is computed and the probability of an exceedance determined. The guidance suggests that the 98th percentile confidence level should be used to indicate if an exceedance is likely. The guidance suggests that the assessment should be conducted at the nearest residential receptor or at locations where people are likely to be exposed and that there should be no running time restrictions on these generators when providing power on site during an emergency.

Both the methodology advised in the USEPA guidance as well as the approach described in the UK EA guidance have been applied for the scenarios modelled in this study to ensure a robust assessment of predicted air quality impacts from the standby generators.

According to Appendix E of the EPA guidance note AG4[(4)], cumulative assessments are only required for facilities that will emit over 100 tonnes of a regulated pollutant per annum. There are no facilities within 1 km of the proposed development which meet this criterion for NOx, therefore a cumulative impact assessment is not required.

6.0 RESULTS

6.1 Construction Stage

6.1.1 Air Quality

The greatest potential impact on air quality during the construction phase of the proposed development is from construction dust emissions and the potential for nuisance dust and PM_{10}/$PM_{2.5}$ emissions (Table 5). This can be considered a moderate scale development, however there will be limited use of haul routes, indicating that, as a worst case, there is the potential for significant dust soiling effects 50 m from works areas (see Table 5). While construction dust tends to be deposited within 200 m of a construction site, the majority of the deposition occurs within the first 50 m. There are no sensitive receptors within 200 m of the site boundary. Therefore the air quality impacts during the construction phase will be short-term and imperceptible.

Source		Potential Distance for Significant Effects (Distance From Source)		
Scale	**Description**	**Soiling**	**PM_{10}**	**Vegetation Effects**
Major	Large construction sites, with high use of haul roads	100m	25m	25m
Moderate	Moderate sized construction sites, with moderate use of haul roads	50m	15m	15m
Minor	Minor construction sites, with limited use of haul roads	25m	10m	10m

Table 5 Assessment Criteria for the Impact of Dust from Construction, with Standard Mitigation in Place (TII, 2011)

6.1.2 Climate

There is the potential for a number of greenhouse gas emissions to atmosphere during the construction of the development. Construction vehicles, generators etc., may give rise to CO_2 and N_2O emissions. The Institute of Air Quality Management document *Guidance on the Assessment of Dust from Demolition and Construction* (IAQM, 2014) states that site traffic and plant is unlikely to make a significant impact on climate. Therefore, the impact on climate is considered to be ***imperceptible*** and ***short term.***

6.2 Operational Stage

6.2.1 Emergency Operation & Scheduled Testing (USEPA Methodology)

This assessment involved modelling the continuous operation of the 5 no. standby diesel generators for 100 hours per year based on the USEPA methodology(21) and also considering scheduled testing of the diesel generators. The NO_2 modelling results at the worst-case off-site receptor are detailed in Table 6. The results indicate that the ambient ground level concentrations are in compliance with the relevant air quality standards for NO_2. For the worst-case year, emissions from the site lead to an ambient NO_2 concentration (including background) which is 65% of the maximum ambient 1-hour limit value (measured as a 99.8th percentile) and 56% of the annual limit value at the worst-case off-site receptor.

The geographical variations in ground level NO_2 concentrations beyond the facility boundary for the worst-case years modelled are illustrated as concentration contours in Figures 4 and 5. The locations of the maximum concentrations for NO_2 are close to the boundary of the site with concentrations decreasing with distance from the facility.

Pollutant / Meteorological Year	Averaging Period	Process Contribution NO_2 (µg/m^3)	Background (µg/m^3)	Predicted Emission Concentration NO_2 (µg/m^3)	Standard (µg/m^3) Note 1	PEC as a % of Limit Value
NO_2 / 2017	Annual mean	2.9	17	19.9	40	50%
	99.8th%ile of 1-hr means	90.9	34	124.9	200	62%
NO_2 / 2018	Annual mean	5.4	17	22.4	40	56%
	99.8th%ile of 1-hr means	92.3	34	126.3	200	63%
NO_2 / 2019	Annual mean	3.6	17	20.6	40	51%
	99.8th%ile of 1-hr means	96.7	34	130.7	200	65%
NO_2 / 2020	Annual mean	4.8	17	21.8	40	55%
	99.8th%ile of 1-hr means	92.2	34	126.2	200	63%
NO_2 / 2021	Annual mean	4.6	17	21.6	40	54%
	99.8th%ile of 1-hr means	87.7	34	121.7	200	61%

Note 1 Air Quality Standards 2011 (from EU Directive 2008/50/EC and S.I. 180 of 2011)

Table 6 Dispersion Model Results for Nitrogen Dioxide (NO_2) – Emergency Operations & Scheduled Testing

6.2.2 Emergency Operation (UK EA Methodology)

Emissions from the 5 no. standby generators were assessed using the UK EA methodology. The methodology, based on considering the statistical likelihood of an exceedance of the NO_2 hourly limit value assuming a hypergeometric distribution, has been undertaken at the worst-case residential receptor. The cumulative hypergeometric distribution of 19 and more hours per year was computed and the probability of an exceedance determined as outlined in Table 7. The results have been compared to the 98th percentile confidence level to indicate if an exceedance is likely at various operational hours for the standby diesel generators. The results indicate that in the worst-case year, the emergency generators can operate for up to 2560 hours per year before there is a likelihood of an exceedance of the ambient air quality standard (at a 98th percentile confidence level). Figure 3 shows the statistical distribution predicted for the 98th percentile (based on 2560 hours of operation per year). However, the UK guidance recommends that there should be no running time restrictions placed on back-up generators which provide power on site only during an emergency power outage.

Pollutant / Meteorological Year	Hours of operation (Hours) (98th%ile) Allowed Prior To Exceedance Of Limit Value	UK Guidance – Probability Value = 0.02 (98th%ile)$^{Note 1}$
NO_2 / 2017	8760	0.02
NO_2 / 2018	2560	
NO_2 / 2019	5610	
NO_2 / 2020	4980	
NO_2 / 2021	4280	

Note 1 Guidance Outlined In UK EA publication "Diesel Generator Short-Term NO_2 Impact Assessment"[21]

Table 7 Hypergeometric Statistical Results at Worst-Case Residential Receptor – NO_2

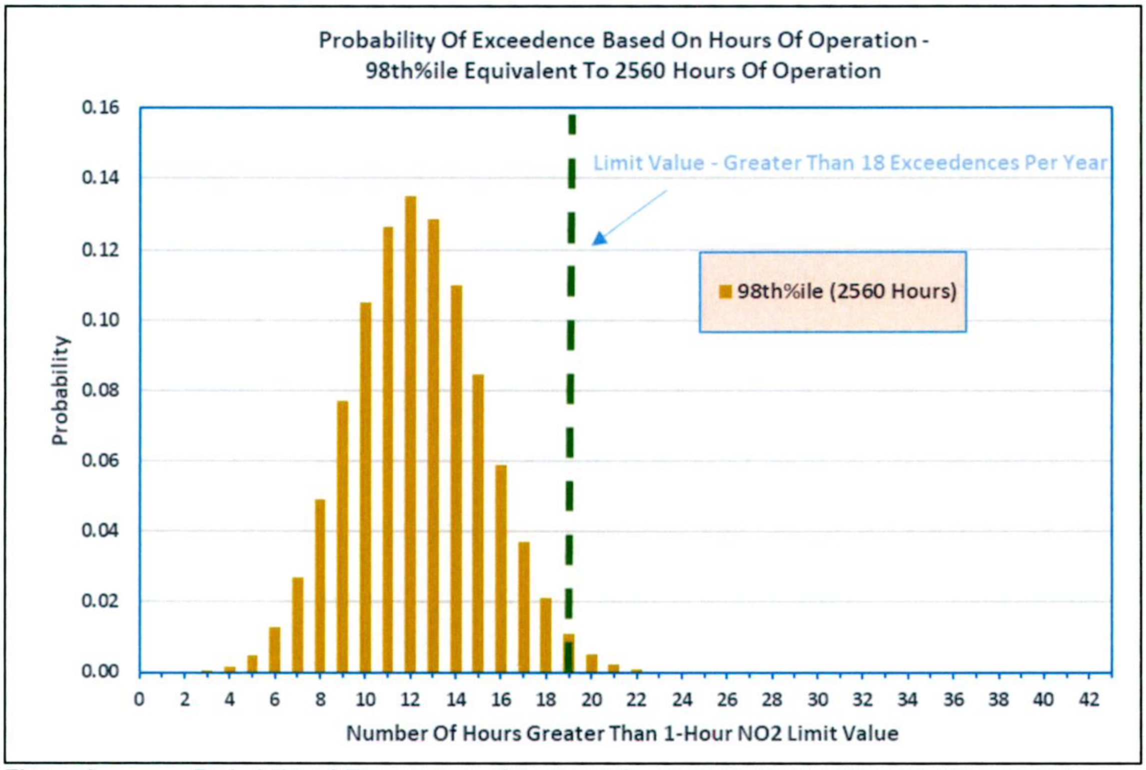

Figure 3 Probability of Exceedance of 1-Hour NO_2 Ambient Air Quality Limit Value based on Hours of Operation of Back-up Diesel Generators

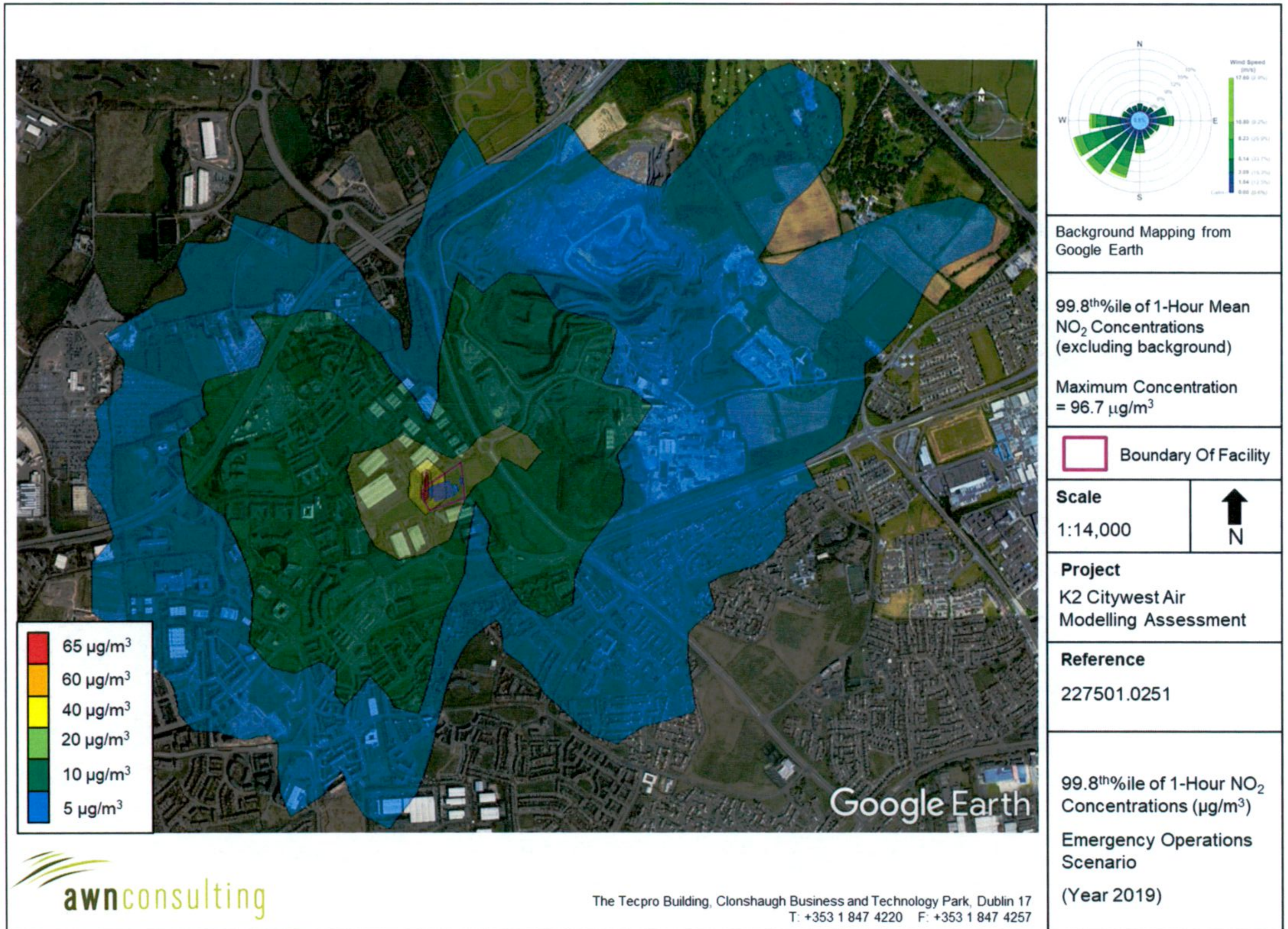

Figure 4 Emergency Operations - Maximum 1-Hour NO_2 Concentrations (as 99.8th%ile) (µg/m³) 2019 (excluding background concentrations)

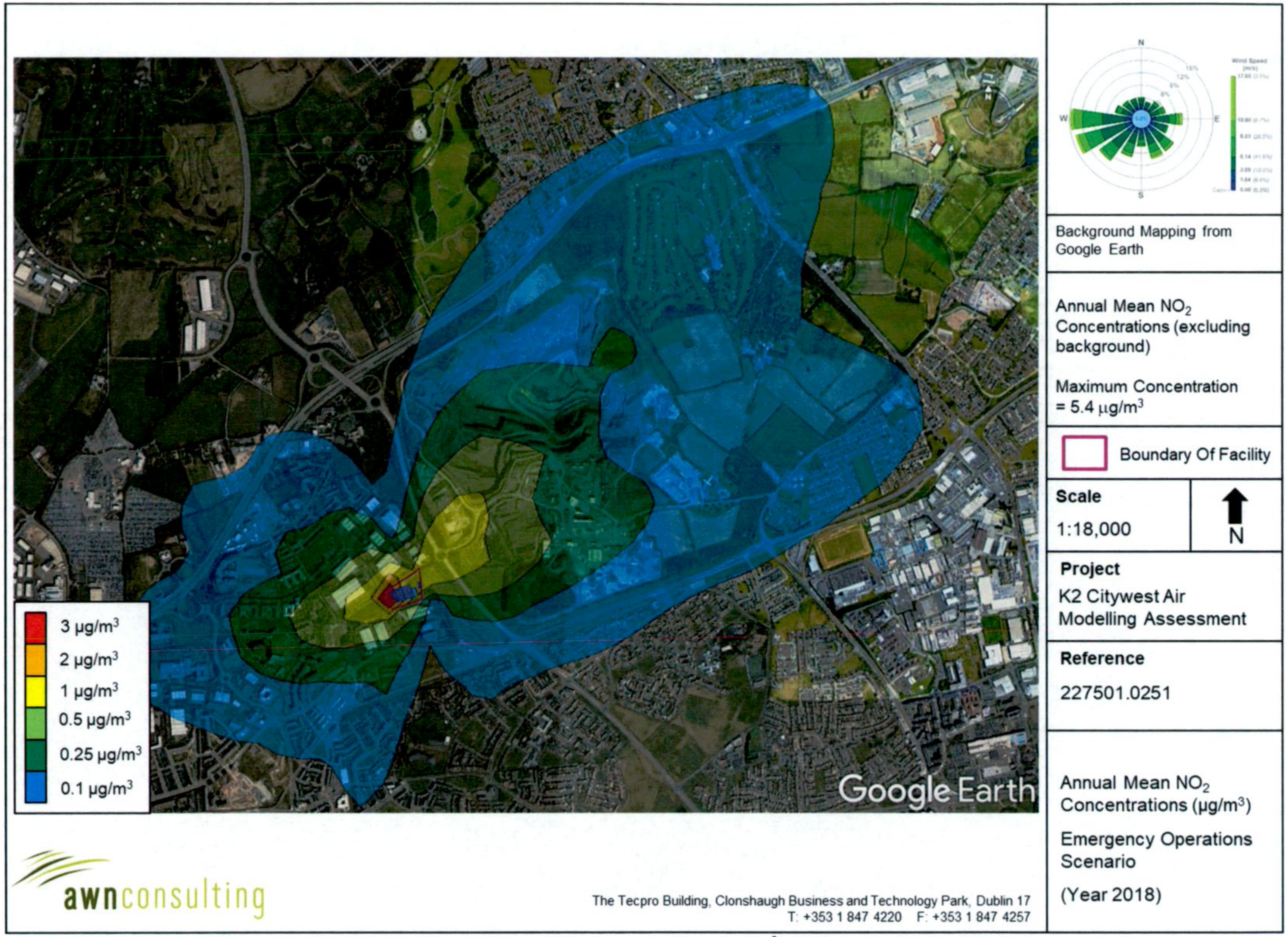

Figure 5 Emergency Operations - Annual Mean NO_2 Concentrations (µg/m³) 2018 (excluding background concentrations)

6.2.4 Climate Assessment

The back-up diesel generators modelled for the purpose of this assessment will only be used in the event of a power failure at the site and for testing purposes. During normal operations at the facility, the electricity will be supplied from the national grid. Electricity to operate the facility will be purchased from the available energy suppliers including power stations and renewable generation sources such as wind power.

The indirect CO_2 emissions from electricity to operate the facility will not be significant in relation to Ireland's national annual CO_2 emissions. The Sustainable Energy Authority of Ireland(23) states on its website that the average CO_2 emission factor for electricity generated in Ireland was 296 gCO_2/kWh in 2020. This average CO_2 emission factor is based on the national power generating portfolio. On the basis that the proposed development will consume a maximum of 10 MW of electricity, this equates to 88 GWh annually for based on the assumption of the national fuel mix. This translates to approximately 25,912 tonnes of CO_2eq per year.

Electricity providers form part of the EU-wide Emission Trading Scheme (ETS) and thus greenhouse gas emissions from these electricity generators are not included when determining compliance with the targeted 42% reduction in the non-ETS sector i.e. electricity associated greenhouse gas emissions will not count towards the Effort Sharing Decision target. Thus, any necessary increase in electricity generation due to data centre demand will have no impact on Ireland's obligation to meet the EU Effort Sharing Decision. Under this scenario, as outlined in the Regulation, the new electricity provider will be treated as a "new entrant" under Phase IV of the ETS (i.e. an electricity generator obtaining a greenhouse gas emissions permit for the first time after 30th June 2018). The new electricity provider will be required to purchase allocations in the same manner as existing players in the market using the European Energy Exchange. EU leaders have also decided that during Phase IV (2021-2030) 90% of the revenue from the auctions will be allocated to the Member States on the basis of their share of verified emissions with 10% allocated to the least wealthy EU member states. The revised EU ETS Directive has enshrined in law the requirement that at least 50% of the auctioning revenues or the equivalent in financial value should be used for climate and energy related purposes.

In 2018, the market reported a fall of 4.1% (73 million tonnes CO_2eq) from 2017, the EU noted that much of the revenue raised by the cap and trade scheme is going towards climate and energy objectives(27):

"In 2018, a strengthened carbon price signal led to a record amount of revenues for Member States from the selling of ETS allowances. The generated amount equalled some EUR 14 billion - more than doubling the revenues generated in 2017. Member States spent or planned to spend close to 70% of these revenues on advancing climate and energy objectives - well above the 50% required in the legislation"

In terms of wider energy policy, as outlined in the EPA publication "Ireland's Greenhouse Gas Projections 2020-2040"(28) under the With Additional Measures scenario, emissions from the energy industries sector are projected to decrease by 25% to 6.3 Mt CO_2eq over the period 2020 to 2030 including the proposed increase in renewable energy generation to approximately 70% of electricity consumption:

- "In this scenario it is assumed that for 2020 there is a 40% share of renewable energy in electricity generation. In 2030 it is estimated that renewable energy generation increases to approximately 70% of electricity consumption. This is mainly a result of further expansion in wind energy (comprising 3.5 GW offshore and approximately 8.2 GW onshore). Expansion of other renewables (e.g. solar photovoltaics) also occurs under this scenario;

- Under the With Additional Measures scenario The operation of three peat plants used for electricity generation until the end of 2020 only are included in the assumptions underpinning the energy projections following which just one plant continues to operate. One peat station continues to operate until planning permission expires in 2023, cofiring with 30% biomass;

- In this scenario the Moneypoint power station is assumed to operate in the market up to end 2024 at which point it no longer generates electricity from coal as set out in the 2019 Climate Action Plan; and

- In terms of inter-connection, it is assumed that the Greenlink 500MW interconnector to the UK to come on stream in 2025 and the Celtic 700MW interconnector to France to come on stream in 2026".

Data centres are typically 84% more efficient than on-premises servers and the GHG savings associated with this are not included in the GHG emissions total. In addition, in terms of total forecasted capacity, it is predicted that 1,700MW of data centres capacity will be operational by 2025 in Ireland. However, the carbon intensity of electricity is predicted to decrease from 331 gCO_2/kWh in 2019 to 100 gCO_2/kWh in 2030 as a result of the increase in renewables to 70% of the electricity market by 2030. Overall, it is predicted that data centres will peak at 2.2% of total GHG emissions in 2024 and will fall or level off after this date.

As the proposed development is over 20 MW, a greenhouse gas emission permit will be required for the facility which will be regulated under the EU-wide Emission Trading Scheme (ETS). Electricity providers form part of the ETS and thus greenhouse gas emissions from these electricity generators are not included when determining compliance with the targeted 20% reduction in the non-ETS sector i.e. electricity associated greenhouse gas emissions will not count towards the Effort Sharing Decision target. Thus, any necessary increase in electricity generation due to data centre demand will have no impact on Ireland's obligation to meet the EU Effort Sharing Decision. On an EU-wide basis, where the ETS market in 2021 is approximately 1,355 million tonnes CO_2eq, the impact of the emissions associated with the proposed data centre development will be less than 0.01% of the total EU-wide ETS market which is imperceptible.

Thus, given that the use of electricity to power the facility will achieve net zero by 2050 and the commitment to offset all interim fossil fuel derived GHG emissions by the purchase of renewable electricity from SSE Airtricity the predicted impact to climate is deemed to be indirect, long-term, negative and slight.

7.0 ASSESSMENT SUMMARY

7.1 Construction Stage

There are no sensitive receptors within 200 m of the site boundary. Therefore impacts on air quality will be short-term and imperceptible.

7.2 Operational Stage

The results indicate that ambient ground level concentrations are below the relevant air quality standards for NO_2 for all scenarios modelled. Emissions associated with the 5 no. standby generators lead to an ambient NO_2 concentration that is 65% of the ambient 1-hour limit value (measured as a 99.8^{th} percentile) and 56% of the ambient annual mean limit value at the worst case off-site receptor for the worst case year.

The UKEA assessment methodology determined that the standby generators could operate for 2560 hours before there is a likelihood of an exceedance of the ambient air quality standard (at a 98^{th} percentile confidence level). However, the UK guidance recommends that there should be no running time restrictions placed on standby generators which provide power on site only during an emergency power outage.

In summary, impacts on ambient air quality associated with the standby generators at the proposed development site will be in compliance with the ambient air quality standards which are based on the protection of the environment and human health.

The climate assessment determined that based on the proposed development consuming a maximum of 10 MW of electricity, it will indirectly generate 25,912 tonnes of CO_2eq per year. This will have an overall indirect, long-term and slight negative impact on climate.

However, electricity providers form part of the EU-wide Emission Trading Scheme (ETS) and thus greenhouse gas emission from these electricity generators are not included when determining compliance with the targeted 42% reduction in the non-ETS sector. Thus, emissions from electricity generators will not affect the EU 2030 target of a 42% reduction in non-Emission Trading Scheme (non-ETS) greenhouse gas emissions by 2030. Consequently, the proposed development will have no impact on whether Ireland meets the targets set for 2030. The use of electricity to power the facility will achieve net zero by 2050 and the facility also commits to to offset all interim fossil fuel derived GHG emissions by the purchase of renewable electricity from SSE Airtricity.

No significant impacts to either air quality or climate are predicted as a result of the proposed development.

8.0 REFERENCES

(1) German VDI (2002) Technical Guidelines on Air Quality Control – TA Luft
(2) DOEHLG (2004) Quarries and Ancillary Activities, Guidelines for Planning Authorities
(3) USEPA (2019) AERMOD Description of Model Formulation and Evaluation
(4) EPA (2020) Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)
(5) USEPA (1995) User's Guide for the Industrial Source Complex (ISC3) Dispersion Model Vol I & II
(6) USEPA (2005) Guidelines on Air Quality Models, Appendix W to Part 51, 40 CFR Ch.1
(7) USEPA (2000) Seventh Conference on Air Quality Modelling (June 2000) Vol I & II
(8) USEPA (1998) Human Health Risk Assessment Protocol, Chapter 3: Air Dispersion and Deposition Modelling, Region 6 Centre for Combustion Science and Engineering
(9) USEPA (1999) Comparison of Regulatory Design Concentrations: AERMOD vs. ISCST3 vs. CTDM PLUS
(10) Schulman, L.L; Strimaitis, D.G.; Scire, J.S. (2000) Development and evaluation of the PRIME plume rise and building downwash model. Journal of the Air & Waste Management Association, 50, 378-390.
(11) Paine, R & Lew, F. "Consequence Analysis for Adoption of PRIME: an Advanced Building Downwash Model" Prepared for the EPRI, ENSR Document No. 2460-026-450 (1997).
(12) Paine, R & Lew, F. "Results of the Independent Evaluation of ISCST3 and ISC-PRIME" Prepared for the EPRI, ENSR Document No. 2460-026-3527-02 (1997).
(13) USEPA (2017) AERMAP Users Guide
(14) Met Éireann (2022) Met Éireann Website: www.met.ie
(15) USEPA (2018) User's Guide to the AERMOD Meteorological Preprocessor (AERMET)
(16) USEPA (2008) AERSURFACE User's Guide
(17) Alaska Department of Environmental Conservation (2008) ADEC Guidance re AERMET Geometric Means (http://dec.alaska.gov/air/ap/modeling.htm)
(18) USEPA (1985) Good Engineering Practice Stack Height (Technical Support Document For The Stack Height Regulations) (Revised)
(19) EPA (2020) http://www.epa.ie/whatwedo/monitoring/air/
(20) Environmental Protection Agency (2021) Air Quality Monitoring Report 2020 (& previous reports)
(21) UK Environment Agency (2016) Air Quality Modelling and Assessment Unit – Diesel Generator Short Term NO_2 Impact Assessment
(22) USEPA (2011) Additional Clarification Regarding Application of Appendix W Modelling Guidance for the 1-Hour National Ambient Air Quality Standard
(23) SEAI (2022) https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/
(24) EPA (2022) Ireland's Final Greenhouse Gas Emissions 1990 – 2020
(25) Hanrahan, P (1999a) The Plume Volume Molar Ratio Method for Determining NO2/NOX Ratios in Modelling – Part 1: Methodology J. Air & Waste Management Assoc. 49 1324-1331.
(26) Hanrahan, P (1999b) The Plume Volume Molar Ratio Method for Determining NO_2/NO_X Ratios in Modelling – Part 21: Evaluation Studies J. Air & Waste Management Assoc. **49** 1332-1338.
(27) European Commission (2019) website: https://ec.europa.eu/clima/news/carbon-market-report-emissions-eu-ets-stationary-installations-fall-more-4_en

(28) Environmental Protection Agency (2021) GHG Emissions Projections Report - Ireland's Greenhouse Gas Emissions Projections 2020 – 2040

APPENDIX I

Description of the AERMOD Model

The AERMOD dispersion model has been developed in part by the U.S. Environmental Protection Agency (USEPA)[3,6]. The model is a steady-state Gaussian model used to assess pollutant concentrations associated with industrial sources. The model is an enhancement on the Industrial Source Complex-Short Term 3 (ISCST3) model which has been widely used for emissions from industrial sources.

Improvements over the ISCST3 model include the treatment of the vertical distribution of concentration within the plume. ISCST3 assumes a Gaussian distribution in both the horizontal and vertical direction under all weather conditions. AERMOD with PRIME, however, treats the vertical distribution as non-Gaussian under convective (unstable) conditions while maintaining a Gaussian distribution in both the horizontal and vertical direction during stable conditions. This treatment reflects the fact that the plume is skewed upwards under convective conditions due to the greater intensity of turbulence above the plume than below. The result is a more accurate portrayal of actual conditions using the AERMOD model. AERMOD also enhances the turbulence of night-time urban boundary layers thus simulating the influence of the urban heat island.

In contrast to ISCST3, AERMOD is widely applicable in all types of terrain. Differentiation of the simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions. In the dividing-streamline concept, flow below this height remains horizontal, and flow above this height tends to rise up and over terrain. Extensive validation studies have found that AERMOD (precursor to AERMOD with PRIME) performs better than ISCST3 for many applications and as well or better than CTDMPLUS for several complex terrain data sets[10].

Due to the proximity to surrounding buildings, the PRIME (Plume Rise Model Enhancements) building downwash algorithm has been incorporated into the model to determine the influence (wake effects) of these buildings on dispersion in each direction considered. The PRIME algorithm takes into account the position of the stack relative to the building in calculating building downwash. In the absence of the building, the plume from the stack will rise due to momentum and/or buoyancy forces. Wind streamlines act on the plume leads to the bending over of the plume as it disperses. However, due to the presence of the building, wind streamlines are disrupted leading to a lowering of the plume centreline.

When there are multiple buildings, the building tier leading to the largest cavity height is used to determine building downwash. The cavity height calculation is an empirical formula based on building height, the length scale (which is a factor of building height & width) and the cavity length (which is based on building width, length and height). As the direction of the wind will lead to the identification of differing dominant tiers, calculations are carried out in intervals of 10 degrees.

In PRIME, the nature of the wind streamline disruption as it passes over the dominant building tier is a function of the exact dimensions of the building and the angle at which the wind approaches the building. Once the streamline encounters the zone of influence of the building, two forces act on the plume. Firstly, the disruption caused by the building leads to increased turbulence and enhances horizontal and vertical dispersion. Secondly, the streamline descends in the lee of the building due to the reduced pressure and drags the plume (or part of) nearer to the ground, leading to higher ground level concentrations. The model calculates the descent of the plume as a function of the building shape and, using a numerical plume rise model, calculates the change in the plume centreline location with distance downwind.

The immediate zone in the lee of the building is termed the cavity or near wake and is characterised by high intensity turbulence and an area of uniform low pressure. Plume mass captured by the cavity region is re-emitted to the far wake as a ground-level volume source. The volume source is located at the base of the lee wall of the building, but is only evaluated near the end of the near wake and beyond. In this region, the disruption caused by the building downwash gradually fades with distance to ambient values downwind of the building.

AERMOD has made substantial improvements in the area of plume growth rates in comparison to ISCST3[3,5]. ISCST3 approximates turbulence using six Pasquill-Gifford-Turner Stability Classes and bases the resulting dispersion curves upon surface release experiments. This treatment, however, cannot explicitly account for turbulence in the formulation. AERMOD is based on the more realistic modern planetary boundary layer (PBL) theory which allows turbulence to vary with height. This use of turbulence-based plume growth with height leads to a substantial advancement over the ISCST3 treatment.

Improvements have also been made in relation to mixing height[3,5]. The treatment of mixing height by ISCST3 is based on a single morning upper air sounding each day. AERMOD, however, calculates mixing height on an hourly basis based on the morning upper air sounding and the surface energy balance, accounting for the solar radiation, cloud cover, reflectivity of the ground and the latent heat due to evaporation from the ground cover. This more advanced formulation provides a more realistic sequence of the diurnal mixing height changes.

AERMOD also has the capability of modelling both unstable (convective) conditions and stable (inversion) conditions. The stability of the atmosphere is defined by the sign of the sensible heat flux. Where the sensible heat flux is positive, the atmosphere is unstable whereas when the sensible heat flux is negative the atmosphere is defined as stable. The sensible heat flux is dependent on the net radiation and the available surface moisture (Bowen Ratio). Under stable (inversion) conditions, AERMOD has specific algorithms to account for plume rise under stable conditions, mechanical mixing heights under stable conditions and vertical and lateral dispersion in the stable boundary layer.

AERMOD also contains improved algorithms for dealing with low wind speed (near calm) conditions. As a result, AERMOD can produce model estimates for conditions when the wind speed may be less than 1 m/s, but still greater than the instrument threshold.

APPENDIX II

Meteorological Data - AERMET

AERMOD incorporates a meteorological pre-processor AERMET (version 16216)[14]. AERMET allows AERMOD to account for changes in the plume behaviour with height. AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov length, convective velocity scale, convective (CBL) and stable boundary layer (SBL) height and surface heat flux. AERMOD uses this information to calculate concentrations in a manner that accounts for changes in dispersion rate with height, allows for a non-Gaussian plume in convective conditions, and accounts for a dispersion rate that is a continuous function of meteorology.

The AERMET meteorological preprocessor requires the input of surface characteristics, including surface roughness (z_0), Bowen Ratio and albedo by sector and season, as well as hourly observations of wind speed, wind direction, cloud cover, and temperature. A morning sounding from a representative upper air station, latitude, longitude, time zone, and wind speed threshold are also required.

Two files are produced by AERMET for input to the AERMOD dispersion model. The surface file contains observed and calculated surface variables, one record per hour. The profile file contains the observations made at each level of a meteorological tower, if available, or the one-level observations taken from other representative data, one record level per hour.

From the surface characteristics (i.e. surface roughness, albedo and amount of moisture available (Bowen Ratio)) AERMET calculates several boundary layer parameters that are important in the evolution of the boundary layer, which, in turn, influences the dispersion of pollutants. These parameters include the surface friction velocity, which is a measure of the vertical transport of horizontal momentum; the sensible heat flux, which is the vertical transport of heat to/from the surface; the Monin-Obukhov length which is a stability parameter relating the surface friction velocity to the sensible heat flux; the daytime mixed layer height; the nocturnal surface layer height and the convective velocity scale which combines the daytime mixed layer height and the sensible heat flux. These parameters all depend on the underlying surface.

The values of albedo, Bowen Ratio and surface roughness depend on land-use type (e.g., urban, cultivated land etc) and vary with seasons and wind direction. The assessment of appropriate land-use types was carried out in line with USEPA recommendations[6] and using the detailed methodology outlined by the Alaska Department of Environmental Conservation[16]. AERMET has also been updated to allow for an adjustment of the surface friction velocity (u*) for low wind speed stable conditions based on the work of Qian and Venkatram (BLM, 2011). Previously, the model had a tendency to over-predict concentrations produced by near-ground sources in stable conditions.

Surface roughness

Surface roughness length is the height above the ground at which the wind speed goes to zero. Surface roughness length is defined by the individual elements on the landscape such as trees and buildings. In order to determine surface roughness length, the USEPA recommends that a representative length be defined for each sector, based on an upwind area-weighted average of the land use within the sector, by using the eight land use categories outlined by the USEPA. The inverse-distance weighted surface roughness length derived from the land use classification within a radius of 1km from Casement Aerodrome Meteorological Station is shown in Table A1.

Sector	Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter Note 1
0-360	100% Grassland	0.05	0.1	0.01	0.01

Note 1: Winter defined as periods when surfaces covered permanently by snow whereas autumn is defined as periods when freezing conditions are common, deciduous trees are leafless and no snow is present (Iqbal (1983))[(A6)]. Thus for the current location autumn more accurately defines "winter" conditions at the proposed facility.

Table A1 Surface Roughness based on an inverse distance area-weighted average of the land use within a 1km radius of Casement Aerodrome .

Albedo

Noon-time Albedo is the fraction of the incoming solar radiation that is reflected from the ground when the sun is directly overhead. Albedo is used in calculating the hourly net heat balance at the surface for calculating hourly values of Monin-Obuklov length. The area-weighted arithmetic mean albedo derived from the land use classification over a 10km x 10km area centred on Casement Aerodrome is shown in Table A2.

Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter Note 1
0.5% Water, 30% Urban, 0.5% Coniferous Forest, 38% Grassland, 19% Cultivated Land	0.155	0.18	0.187	0.187

Note 1: For the current location autumn more accurately defines "winter" conditions at the proposed facility.

Table A2 Albedo based on an area-weighted arithmetic mean of the land use over a 10km x 10km area centred on Casement Aerodrome .

Bowen ratio

The Bowen ratio is a measure of the amount of moisture at the surface of the earth. The presence of moisture affects the heat balance resulting from evaporative cooling which, in turn, affects the Monin-Obukhov length which is used in the formulation of the boundary layer. The area-weighted geometric mean Bowen ratio derived from the land use classification over a 10km x 10km area centred on Casement Aerodrome is shown in Table A3.

Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter Note 1
0.5% Water, 30% Urban, 0.5% Coniferous Forest, 38% Grassland, 19% Cultivated Land	0.549	1.06	1.202	1.202

Note 1: For the current location autumn more accurately defines "winter" conditions at the proposed facility.

Table A3 Bowen Ratio based on an area-weighted geometric mean of the land use over a 10km x 10km area centred on Casement Aerodrome .