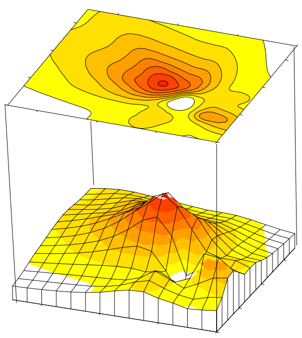
Sulphur Dioxide (SO_2) Emissions Modelling for the New LNG Plant at Delimara Power Station, Malta
Phase 2

P1521

A Report Prepared for
ADI Associates
by

ADM Ltd
Old Chambers
93-94 West Street
Farnham
Surrey
GU9 7EB, UK
Tel: +44 (0) 1252 720842

Email: post@ADMLtd.com
Web: www.AboutAir.com



Principal Author: David Harvey BSc MBA FIAQM
Client: ADI Associates

Version/File	Issue Date
File=P1521\text\Delimara_Phase_2_AQ_v1.doc	20 September 2016
File=P1521\text\Delimara_Phase_2_AQ_v2.doc	21 September 2016

1 INTRODUCTION

Atmospheric Dispersion Modelling (ADM) Ltd has been commissioned by Adi Associates Environmental Consultants Ltd to undertake dispersion modelling of emissions to atmosphere from the new Liquefied Natural Gas (LNG) power station at Delimara, Malta.

An air quality assessment for the proposed power station was completed in August 2013 and included full assessment of emissions of oxides of nitrogen (NO_x/NO_2) and particulate matter (PM_{10} and $PM_{2.5}$) (1). The report stated emissions of sulphur dioxide (SO_2) would be negligible and therefore was not included in the assessment.

It has subsequently transpired that LNG sulphur (S) fuel content could be up to 30 mg Nm^{-3} (273 k, 101.3 kPa) and therefore should be considered.

Phase 1 of the further modelling worked updated the August 2013 study to includes modelling for sulphur dioxide (SO_2) at the guaranteed maximum fuel sulphur content for emissions from the gas turbines operating in both combined cycle mode (CCGT) and for emissions from the gas turbines operating in open cycle mode (OCGT). OCGT operation will only occur for the first six months.

The **Phase 1** modelling assessment concluded that emissions to atmosphere at the guaranteed maximum fuel sulphur (S) content of 30 mg Nm^{-3} (273 k, 101.3 kPa) are compliant with Regulation 3(3) and therefore no further mitigation measures are required (2).

This report presents the emissions data and predictions for **Phase 2** of the further modelling work which includes modelling of emissions of sulphur dioxide (SO_2) from all the sources which will occur during the post commissioning operation of the facility.

The sources of emissions to atmosphere modelled in this **Phase 2** assessment are:

- 3 x D4 PP GT A1, B1, C1
- D3PP SG Engines 1&2
- D3PP SG Engines 3&4
- D3PP DF Engines 1&2 (gas fired)
- D3PP DF Engines 3&4 (gas fired)
- D3PP GRS Gas Boiler No 1
- D3PP GRS Gas Boiler No 2
- FSU Main Boiler (phase 1 oil)

(1) ERSLI (December 2013) Delimara Gas and Power Combined Cycle Gas Turbine and Liquefied Natural Gas receiving, storage , and re-gasification facilities. Delimara Power Station.
(2) ADM Ltd (16 September 2016) Sulphur Dioxide (SO_2) Emissions Modelling for the New LNG Plant at Delimara Power Station, Malta Phase 1.

- FSU Aux Boiler (phase 2 gas)
- FSU Service diesel gen-set (oil)

The Phase 2 modelling presented in this report is for two scenarios, Case 1 is a temporary condition and Case 2 is the expected routine emissions.

2 REGULATIONS

2.1 INTRODUCTION

The section described the targets used for the determination of sulphur dioxide (SO_2) emission limits for combined cycle gas turbine (CCGT) and open cycle gas turbine (OCGT) operation.

2.2 REGULATION 3(3)

Regulation 3(3) of the Industrial Emissions (Large Combustion Plants) Regulations (LN 11 of 2013) state that:

For combustion plants permitted after 07 January 2013, the minimum stack height which shall be established during the initial permitting process, shall be such that the contribution from these combustion plants does not exceed 3% of the limit values in Annex 7 of the Ambient Air Quality Regulations, for the pollutants specified therein.

Schedule 7 (part AII) of the Ambient Air Quality Regulations (LN 478 of 2010 as amended) define the following limit values for SO_2 in ambient air:

- *One day:125 µg/m3, not to be exceeded more than 3 times a calendar year*
- *One hour:350 µg/m3, not to be exceeded more than 24 times a calendar year*

It is considered that the intention of the Regulation 3(3) was that the 3% percentage was to apply to only annual average concentrations. This was assumed to be the case for the previous study that considered the impacts of nitrogen dioxide (NO_2) which compared the annual average concentration with the 3% of the annual average limit value but not compared the hourly average concentrations with 3% of the hourly average limit value.

It is considered that an appropriate limit value for short term impacts (ie 1 hour and 24 hour averaging periods) is 10 times the long term limit value which in this case would be 30% of the short term Ambient Air Quality Regulations. The factor of 10 between long and short term impacts is used by the UK Environment Agency (EA) in their risk assessment guidance [(1)].

However, for the purpose of this study and as instructed by the former Malta Environment & Planning Authority (now the Planning Authority and the Environment & Resources Authority), the 3% of the limit value will be applied to the daily average ambient limit value of 125 μg m^{-3} not to be exceeded more than 3 times per calendar year.

The target for emissions of sulphur dioxide (SO_2) that gives rise to an acceptable impact is therefore 3.75 μg m^{-3} as a daily average not to be exceeded more than 3 times per year which is equivalent to a 3.75 μg m^{-3} as 99.17th percentile of daily averages.

(1) https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit.

3 METHODOLOGY

3.1 INTRODUCTION

This section describes the methodology and assumptions made for the modelling. Also described are the emissions data used.

Modelling has been undertaken for worst case operation which assumes continuous emissions from the following sources:

- D4PP (3 stacks)
- D3PP engines (8x engines and 4 combined stacks)
- D3PP GRS boilers (2 stacks)
- FSU main boiler running at low load (horizontal stack)
- FSU CAT service generator (horizontal stack)

In addition to these sources there are 3 small pilot flames located on the Regas plant area. It's expected that total sulphur dioxide (SO_2) emission rate from this sources will be 0.075 mg s^{-1} which is insignificant and will give rise to an negligible impact on air quality and therefore have not been considered further.

Two cases are considered:

- Case (1) Mobilized FSU with the FSU main boiler emission source.
- Case (2) Cold iron FSU with the new auxiliary boiler as active emission source instead of the FSU main boiler.

Case 1 emissions will only occur during the first year of operation and possibly only during the first few weeks. The reason for including modelling of Case 1 emissions is as a provision in case the storm mooring system is not completed and the FSU would need to keep the main boilers in service for sailing off in a storm mooring event. Therefore the impacts on air quality of Case 1 emissions emission are temporary and only included in this assessment for completeness.

3.2 EMISSIONS DATA

Table 3.1 shows the parameters which will describe physical properties of emissions to atmosphere from the stacks, as required for definition of the emissions in dispersion modelling terms.

The main boiler stack and service diesel generator (sources number 10 and 11) have horizontal releases which means there will only be thermal driven plume rise and no momentum driven plume rise. To remove the effect of momentum driven plume rise from the modelling these source have been modelled with an artificially low exit velocity of 0.5 m s^{-1} and a diameter increased to ensure the correct thermal plume rise. This is a conservative way of modelling a horizontal source.

Emissions assume a LNG sulphur (S) fuel concentration of 30 mg Nm^{-3} (273 k, 101.3 kPa).

Table 3.1 Emissions Data

No	Source	Case (1)	Case (2)	UTM Grid Reference [(a)]	Stack Height (m)	Dia (m)	Velocity ($m\ s^{-1}$)	Temp (deg C)	SO_2 ($g\ s^{-1}$)
1	D4 PP GT A1	✓	✓	459765 3965809 459683 3965627	75	2.9	21.4	95.3	0.19
2	D4 PP GT B1	✓	✓	459751 3965799 459669 3965617	75	2.9	21.4	95.3	0.19
3	D4 PP GT C1	✓	✓	459737 3965788 459655 3965606	75	2.9	21.4	95.3	0.19
4	D3PP SG Engines 1&2	✓	✓	460137 3965687 460055 3965505	65	2.1	23.1	170	0.15
5	D3PP SG Engines 3&4	✓	✓	460134 3965685 460052 3965503	65	2.1	23.1	170	0.15
6	D3PP DF Engines 1&2 (gas fired)	✓	✓	460104 3965663 460022 3965481	65	2.1	21.1	170	0.14
7	D3PP DF Engines 3&4 (gas fired)	✓	✓	460101 3965661 460019 3965479	65	2.1	21.1	170	0.14
8	D3PP GRS Gas Boiler No 1	✓	✓	460015 3965649 459933 3965467	10	0.4	12.0	200	0.001
9	D3PP GRS Gas Boiler No 2	✓	✓	460017 3965650 459935 3965468	10	0.4	12.0	200	0.001
10	FSU Main Boiler (phase 1 oil)	✓	-	459772 3965155 459690 3964973	44	2.1	2.0 [(b)]	167	0.44
11	FSU Aux Boiler (phase 2 gas)	-	✓	459772 3965155 459690 3964973	44	2.1	8.0 [(c)]	330	0.03
12	FSU Service diesel gen-set (oil)	✓	✓	459756 3965157 459674 3964975	18	0.52	30.4 [(d)]	465	0.30

(a) UTM grid references are all zone 33 S and are given for two datum, the first (top) datum is ED50 and second is WGS 84. The WGS 84 datum is used in the modelling and the digital terrain data.
(b) Horizontal release, modelled with 0.5 $m\ s^{-1}$ exit velocity and diameter of 4.2 m.
(c) Horizontal release, modelled with 0.5 $m\ s^{-1}$ exit velocity and diameter of 8.4 m.
(d) Horizontal release, modelled with 0.5 $m\ s^{-1}$ exit velocity and diameter of 4.05 m.

Source 12 (FSU CAT diesel engine, oil) will only operate for an estimated 120 hours per year when a storm mooring is forecast. Storm mooring forecasts only occur for strong winds from the south and therefore will not occur the most frequent wind direction which is from the north west (see **Figure 3.2**). Given that it is the north westerly wind direction that given rise to the maximum predicted concentrations it is reasonable to exclude source 12 from the modelling as it will not be operating during meteorological conditions that give rise to the maximum on land concentration.

3.3 FACTORS AFFECTING DISPERSION

There are a number of factors that affect how emissions disperse once released to atmosphere. The four factors having the greatest effect on dispersion are:

- physical characteristics of the emissions
- climate
- terrain
- building downwash

3.3.1 Physical Characteristics of the Emissions

Provided that exhaust gases have sufficient velocity at stack exit to overcome the effects of stack tip downwash, which is almost certainly the case for velocities of 15 m s^{-1} or more, the physical characteristics of the flue gases will determine the amount of plume rise and, hence, the affect on ground level pollutant concentrations. The degree of plume rise usually depends on the greater of the thermal buoyancy or momentum effects. In the case of emissions from the proposed facility, it will be the thermal effects that determine how high the plume will eventually rise. The exit velocities of 21 m s^{-1} and 33 m s^{-1} are sufficient to overcome the effects of stack tip down wash.

3.3.2 Climate

The most important meteorological parameters governing the atmospheric dispersion of pollutants are wind speed, wind direction and atmospheric stability.

- **Wind direction** determines the broad transport of the plume and the sector of the compass into which the plume is dispersed.

- **Wind speed** can affect plume dispersion by increasing the initial dilution of pollutants and inhibiting plume rise.

- **Atmospheric stability** is a measure of the turbulence of the air, particularly of the vertical motions present. For dispersion modelling purposes, one method of classifying stability is by the use of Pasquill Stability categories, A to F. Another is by reference to the surface heat flux present at the ground.

Dispersion models, such as ADMS and AERMOD, do not allocate the degree of atmospheric turbulence into six discrete categories. These models use a parameter known as the Monin-Obukhov length which, together with the wind speed, describes the stability of the atmosphere.

Building Downwash

The presence of buildings can significantly affect the dispersion of the atmospheric emissions. Wind blowing around a building distorts the flow and creates zones of turbulence that are greater than if the building were absent. Increased turbulence causes greater plume mixing; the rise and trajectory of the plume may be depressed generally by the flow distortion. Downwash leads to higher ground level concentrations closer to the stack than those present in the absence of a building.

It is commonly accepted that downwash effects only occur for emissions from stacks that are less than 2.5 to 3 times the height of the building structures. The structures also have to be sufficiently close to the source for their influence to be significant. The US Environmental Protection Agency suggests that the zone of influence around a building extends for a distance of no more than five times the lesser of the structures height or width. The dispersion model ADMS, however, calculates the effect of buildings out to sixty times the building height.

For the 75 m high main stacks only buildings or structures taller than 30 m will effect dispersion sufficiently to warrant inclusion in the modelling. There are no buildings higher than 12 m in the Delimara Power Station. The highest structures on the site are the three Heat Recovery Steam Generators (HRSGs) at the base of the main stacks which will have no effect on emissions from the main stacks.

Emissions to atmosphere from sources that are located on the LNG vessel will be effected by the physical presence of the ship which has been included in the modelling.

Table 3.2 shows the building dimensions included in the modelling to simulate the downwash effects of the LNG vessel.

Table 3.2 Dimensions of Buildings Included in the Modelling

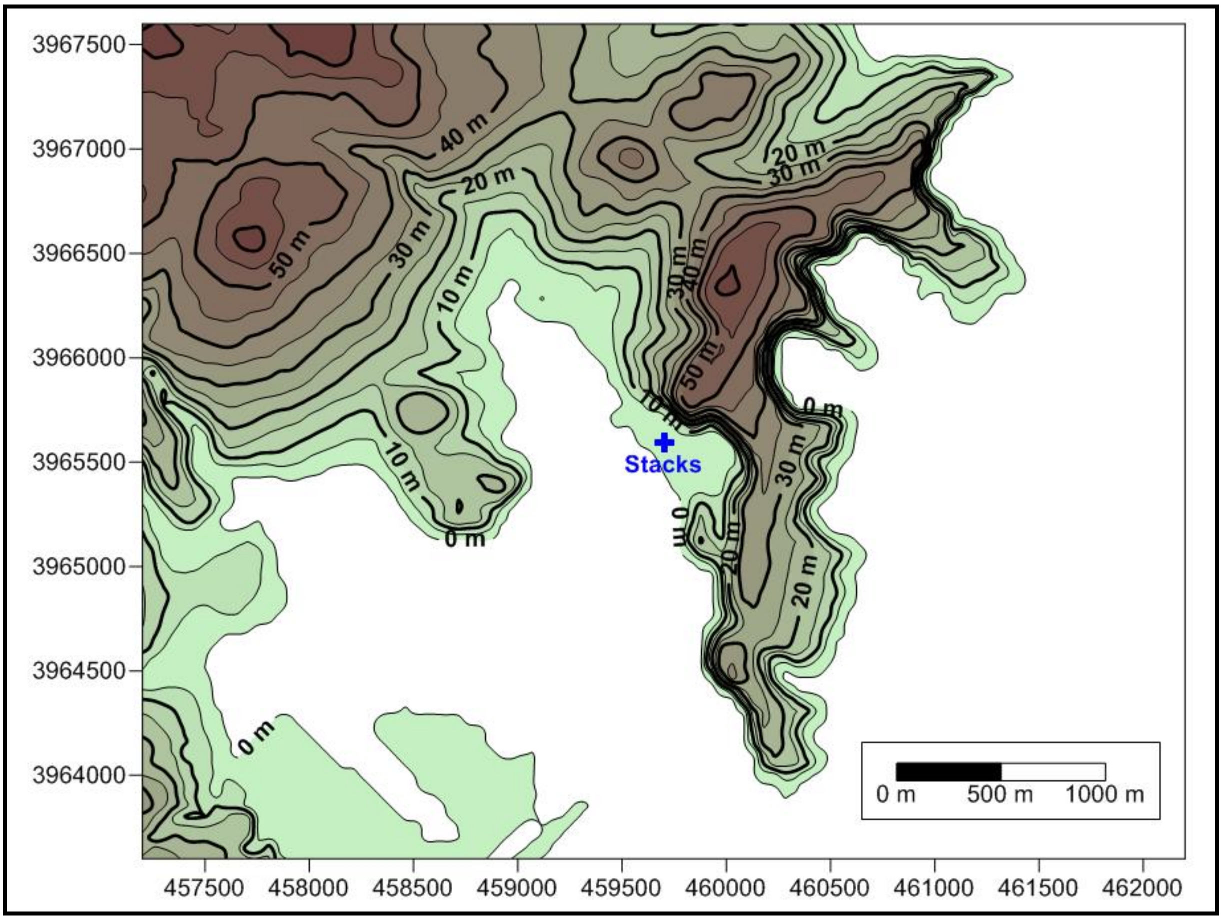
Building	UTM Grid Reference (WGS 84, 33 S, metres)		Height (m)	X Length (m)	Y Length (m)	Angle (deg)
Ship	459750	3965165	30	240	45	90

3.3.3 Nature of the Surface

Terrain

The effects of terrain on dispersion in the region of the facility have been included in the modelling. **Figure 3.1** shows the terrain elevations included in the modelling.

Figure 3.1 Terrain Elevations Included in Modelling (m)



Roughness

The nature of the surface of the terrain can have a significant influence on dispersion by affecting the velocity profile with height and the amount of atmospheric turbulence. To account for the nature of the site and surrounding area, a surface roughness length of 0.3 m to 0.5 m depending on the wind direction has been assumed for the dispersion modelling.

3.3.4 Selection of Suitable Dispersion Model

The dispersion models which are widely used to predict ground level pollutant concentrations are based on the concept of the time averaged lateral and vertical concentration of pollutants in a plume being characterised by a *Gaussian* (1) distribution and the atmosphere is characterised by a number of discrete stability classes. So called 'new generation' dispersion models such as AERMOD and ADMS have been developed which replace the description of the atmospheric boundary layer as being composed of discrete stability classes with an infinitely variable measure of the surface heat flux, which in

(1) A Gaussian distribution has the appearance of a bell shaped curve. The maximum concentration occurs on the centre line.

turn influences the turbulent structure of the atmosphere and hence the dispersion of a plume.

The following are details for two of the commercially available dispersion models that are able to predict ground level concentrations arising from emissions to atmosphere from elevated point sources (ie stacks) which are routinely used for modelling and assessment work.

- *AERMOD*: The US **A**merican Meteorological Society and **E**nvironmental Protection Agency **R**egulatory Model Improvement Committee developed the dispersion **MOD**del called *AERMOD* which incorporates the latest understanding of the atmospheric boundary layer. AERMOD is the US EPA regulatory dispersion model.

- *UK Atmospheric Dispersion Modelling System (ADMS)*: This is a dispersion model developed by the UK consultancy CERC. The model allows for the skewed nature of turbulence within the atmospheric boundary layer.

In many respects the models are quite similar and in many situations generate similar predictions of ground level concentrations. AERMOD was selected as the model for use in this assessment because of its wide spread international acceptability. US EPA version 15181 of AERMOD was used for this assessment.

3.3.5 Meteorological Data

A necessary input to the dispersion model is the meteorological data. These data are important in determining the location of the maximum concentrations and their magnitude. The closest location for which there is observation of all the parameters required for modelling is Malta International Airport, Luqa which is considered to be representative of the location of the proposed development. Luqa is about 5 km to the west of the proposed facility.

Figure 3.2, 3.3 and **3.4** are the 2011-2015 wind roses of the meteorological data used in this assessment, from Luqa. The figures show that the prevailing wind direction is from the north west.

Figure 3.2 Windrose for 2011 and 2012 from Luqa

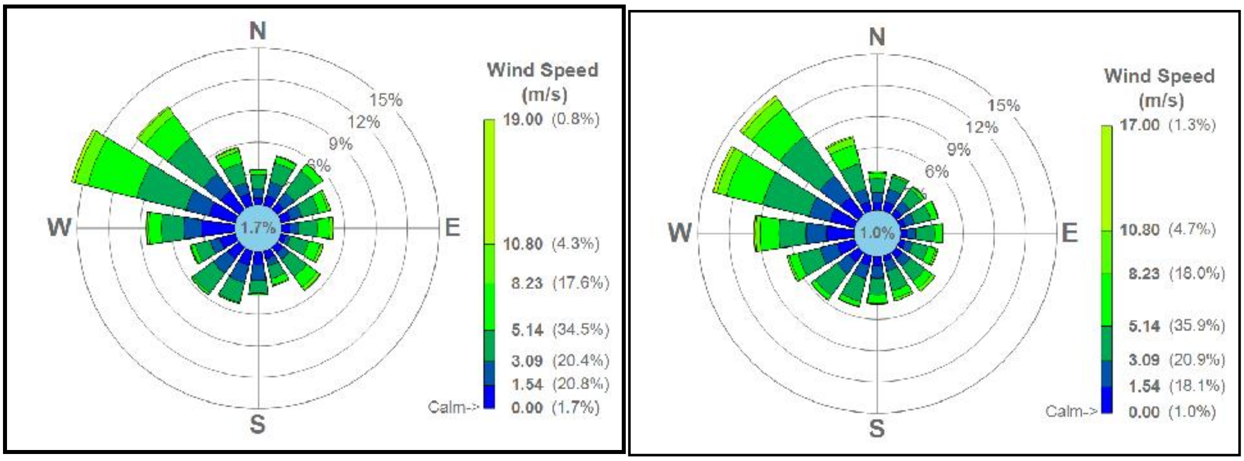


Figure 3.3 Windrose for 2013 and 2014 from Luqa

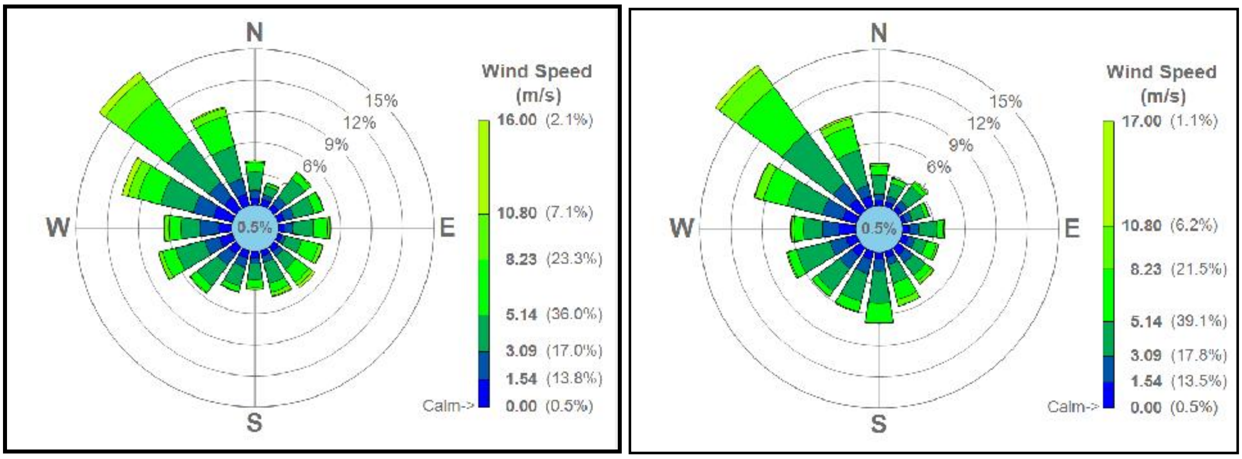
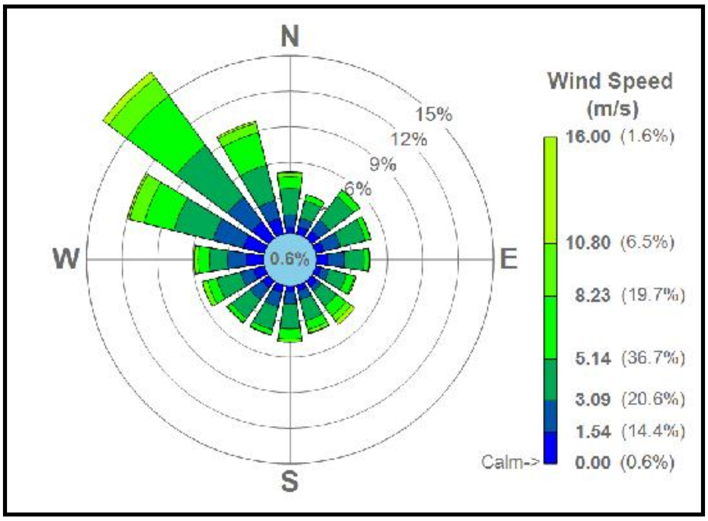


Figure 3.4 Windrose for 2015 from Luqa



3.3.6 Modelling Assumptions

Receptor Grid Spacing

The receptor grid used for this assessment was 5 km by 4 km with a grid spacing of 50 m to allow for predictions to be made at the point of maximum impact.

4 ASSESSMENT OF IMPACTS

4.1 INTRODUCTION

This section describes the predicted ground/sea level concentrations of sulphur dioxide (SO_2) occurring from both operating cases.

Case 1: Emissions during the first year
Case 2: Operation after the first year

See **Section 3.2** for details of the emission sources for each Case.

For compliance with Regulation 3(3) it is considered that only concentrations that occur on land are relevant as there will be no long term (24 hour average) exposure for concentrations occurring over the sea.

4.2 CASE 1

Table 4.1 shows the maximum predicted ground level concentration of sulphur dioxide (SO_2) occurring as a consequence of **Case 1** emissions to atmosphere from the facility operating for each of the five years of meteorological data.

Table 4.1 AERMOD Maximum Predicted Ground Level Concentrations of Sulphur Dioxide (SO_2, $\mu g\ m^{-3}$) for Case 1 Emissions

Year	Annual Average	99.17th Percentile of Daily Average	99.73th Percentile of Hourly Average
2011	1.42	4.9	15.2
2012	1.34	5.0	15.2
2013	1.13	4.6	13.6
2014	1.10	3.9	13.4
2015	1.25	4.7	13.2
Ambient Limit Value	**-**	**125**	**350**
Compliance with Reg. 3(3)	**-**	**3.75**	**-**

Table 4.1 shows that 2012 meteorological data gives rise to the maximum ground level 99.17% percentile of daily average concentrations. The maximum daily average ground level concentration of sulphur dioxide (SO_2) for 2012 of 5.0 $\mu g\ m^{-3}$ is higher than that required for compliance with Regulation 3(3) which is 3.75 $\mu g\ m^{-3}$. Given that Case 1 emissions will occur only during the first year of operation and possibly only during only the first few weeks it is however likely that there will be no exceedence of the Regulation 3(3).

The following figures are presented to show the distribution of ground/sea level concentrations of the sulphur dioxide (SO_2) for Case 1 operation.

Predictions are presented for 2012 which gives rise to the maximum impact for daily average concentrations.

- **Figure 4.1;** Annual Average
- **Figure 4.2**; 99.17th percentile of daily averages

Figure 4.1 AERMOD Predicted Annual Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2012 Meteorological Data ($\mu g\ m^{-3}$); Case 1 Operation

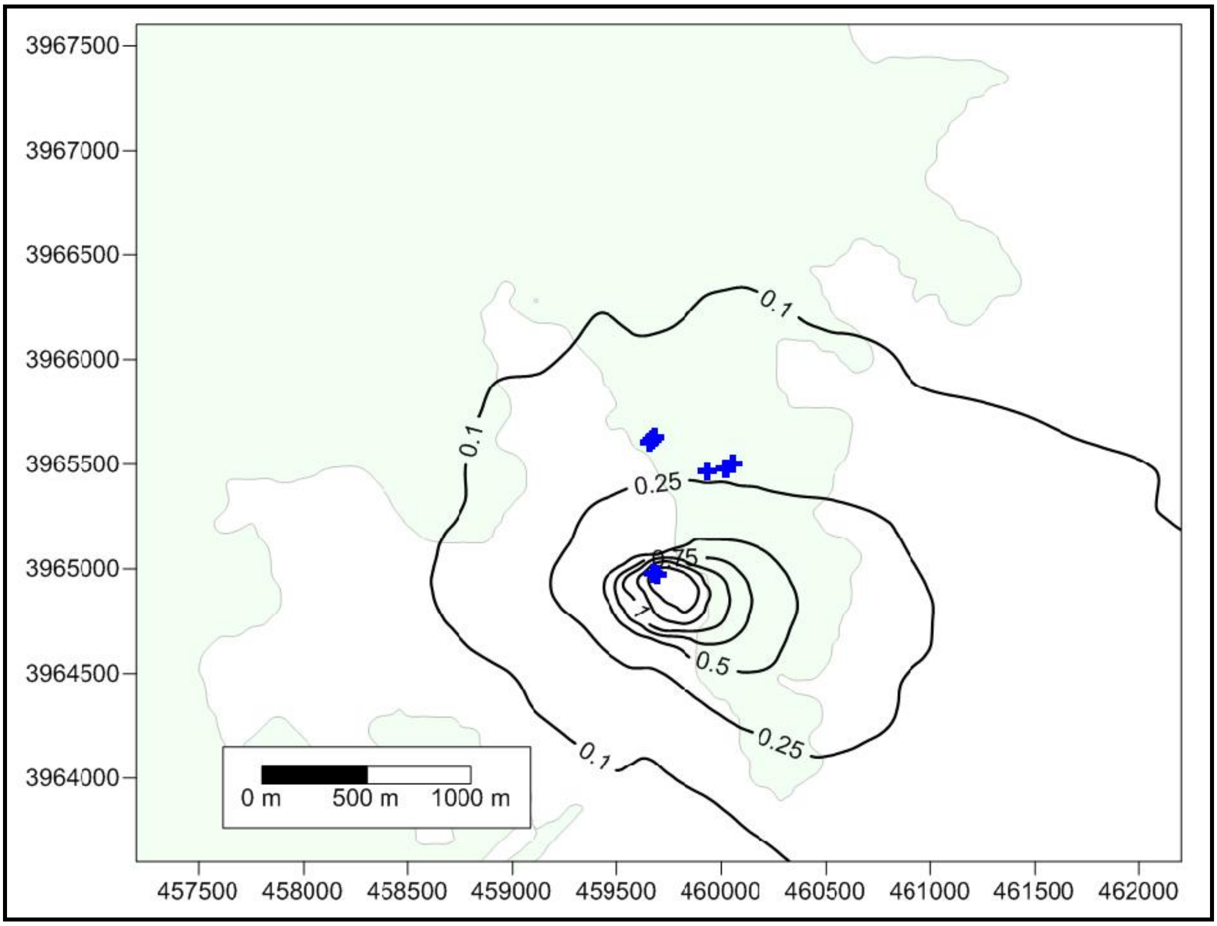
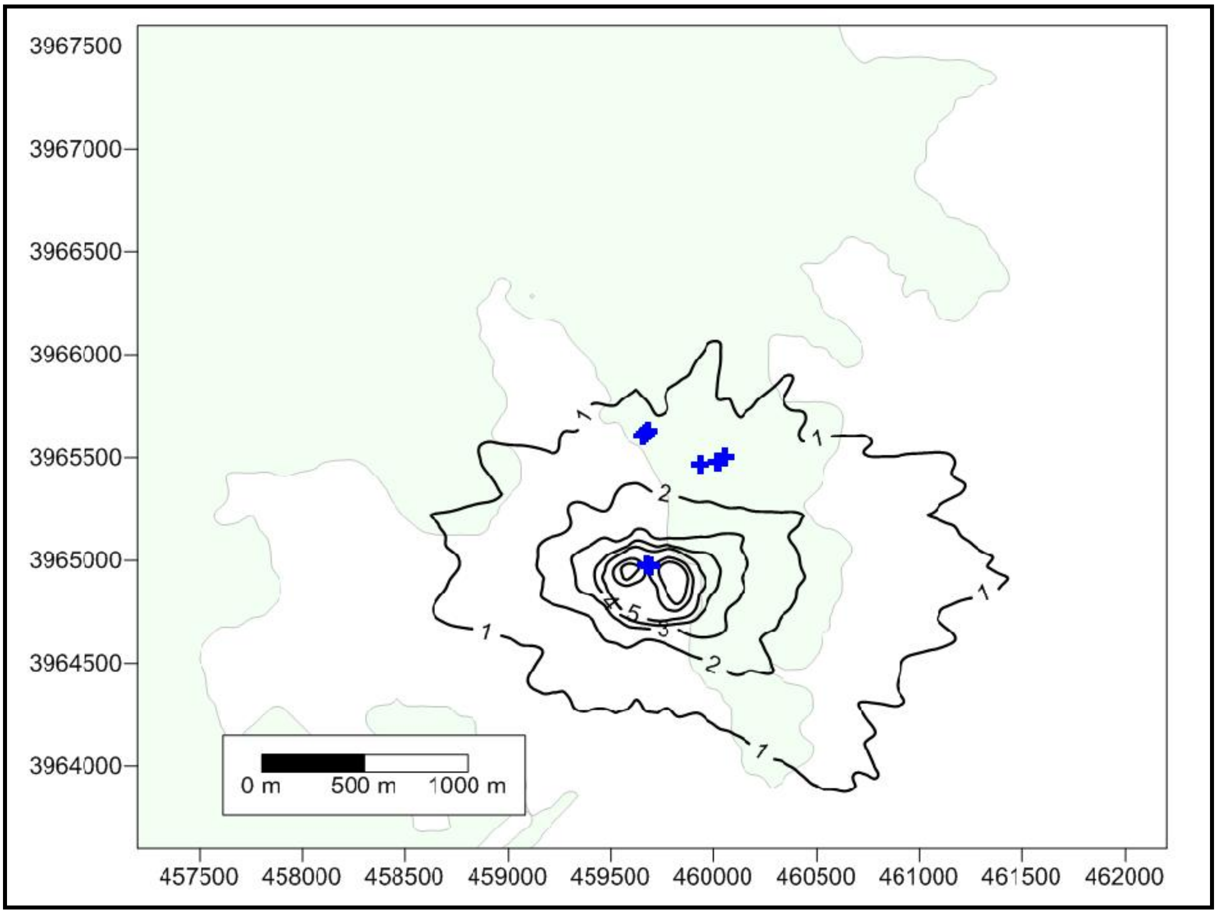


Figure 4.2 AERMOD Predicted 99.17th Percentile of Daily Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2012 Meteorological Data ($\mu g\ m^{-3}$); Case 1 Operation



4.3 CASE 2

Table 4.2 shows the maximum predicted ground level concentration of sulphur dioxide (SO_2) occurring as a consequence of **Case 2** emissions to atmosphere from the facility operating for each of the five years of meteorological data.

Table 4.2 AERMOD Maximum Predicted Ground Level Concentrations of Sulphur Dioxide (SO_2, $\mu g\ m^{-3}$) for Case 2 Emissions

Year	Annual Average	99.17^{th} Percentile of Daily Average	99.73th Percentile of Hourly Average
2011	0.10	0.47	1.0
2012	0.10	0.42	1.0
2013	0.10	0.43	1.0
2014	0.10	0.44	1.0
2015	0.11	0.48	0.9
Ambient Limit Value	**-**	**125**	**350**
Compliance with Reg. 3(3)	**-**	**3.75**	**-**

Table 4.2 shows that 2015 meteorological data gives rise to the maximum ground/sea level 99.17% percentile of daily average concentrations. The maximum daily average ground level concentration of sulphur dioxide (SO_2) for 2015 of 0.48 $\mu g\ m^{-3}$ is substantially less than required for compliance with Regulation 3(3) which is 3.75 $\mu g\ m^{-3}$.

The following figures are presented to show the distribution of ground/sea level concentrations of the sulphur dioxide (SO_2) for **Case 2** operation. Predictions are presented for 2015 which gives rise to the maximum impact for daily average concentration.

- **Figure 4.3;** Annual Average
- **Figure 4.4**; 99.17^{th} percentile of daily averages

Figure 4.3 AERMOD Predicted Annual Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2015 Meteorological Data ($\mu g\ m^{-3}$); Case 2 Operation

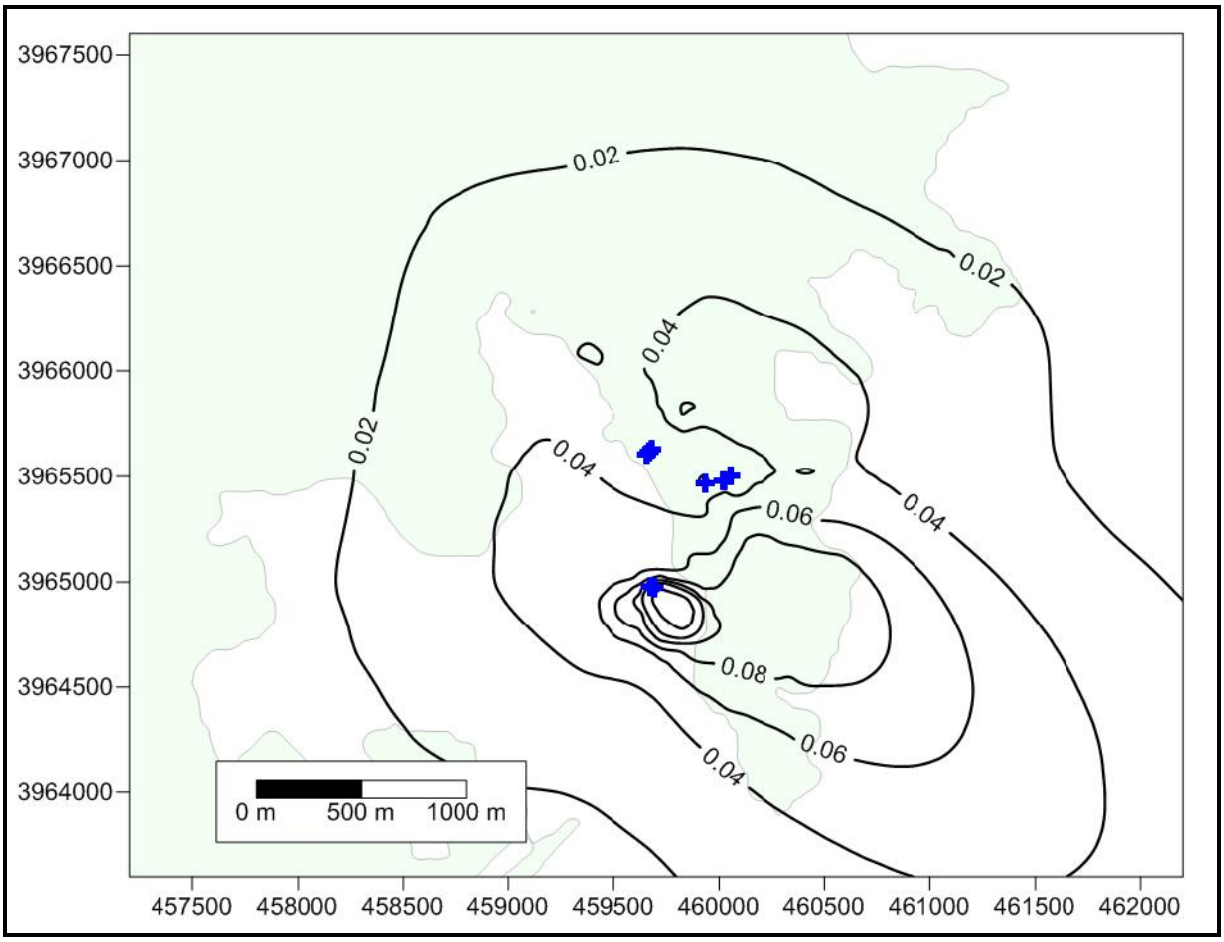
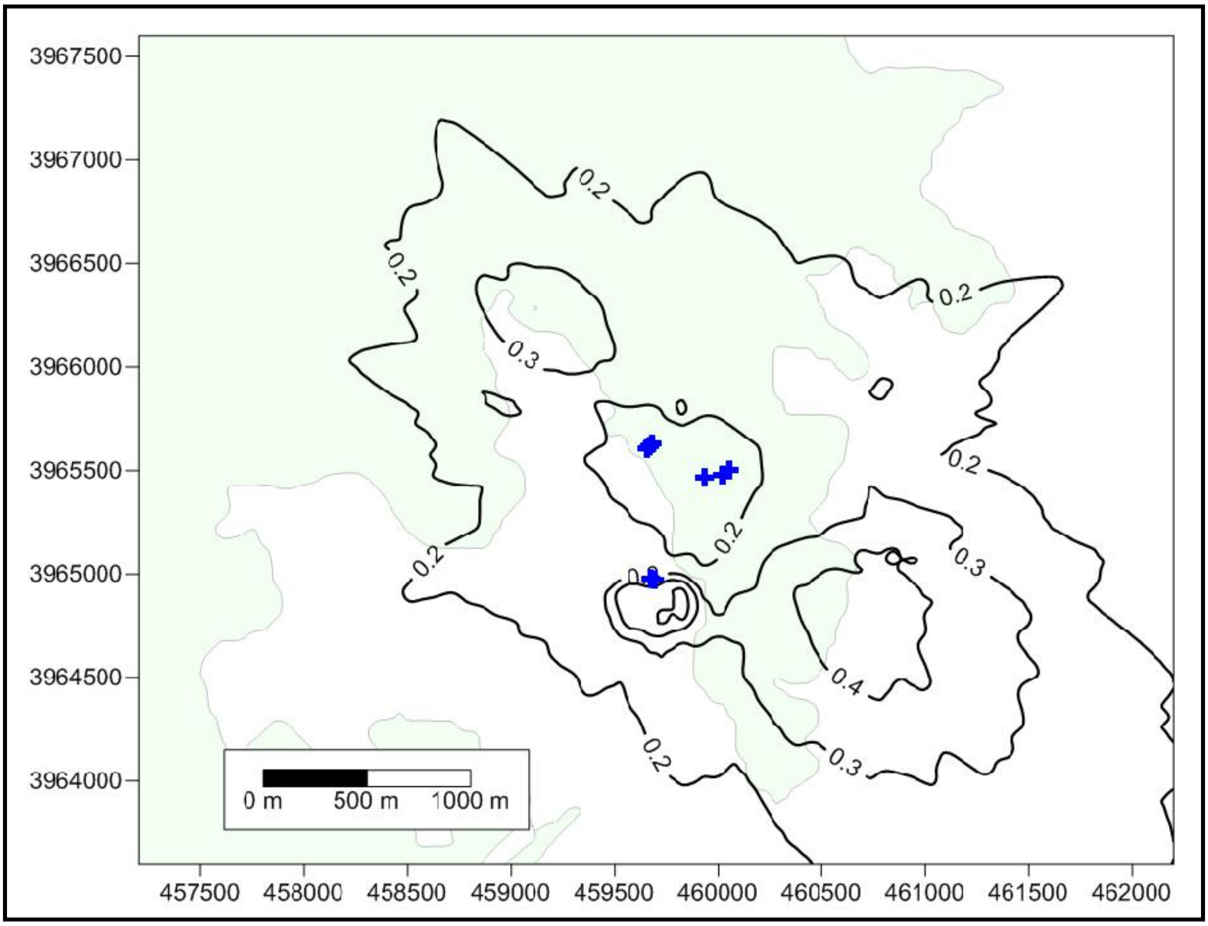


Figure 4.4 AERMOD Predicted 99.17th Percentile of Daily Average Ground/Sea Level Concentrations of the Sulphur Dioxide (SO_2); 2015 Meteorological Data ($\mu g\ m^{-3}$); Case 2 Operation



5 DISCUSSION AND CONCLUSIONS

5.1 INTRODUCTION

This section provides a discussion and conclusions.

5.2 REGULATION 3(3)

It is considered that the intention of Regulation 3(3) was that the 3% criteria should to apply to annual average limit value concentrations and not to short term value concentrations.

For the purpose of this study, the 3% criteria will be applied to the daily average ambient limit value of 125 μg m^{-3} not to be exceeded more than 3 times per calendar year. It is considered that this is a conservative interpretation of the requirements of Regulation 3(3). The former MEPA instructed the Consultants to use this interpretation.

5.3 CASE 1 OPERATION

Case 1 operation will occur for a maximum of one year and possibly only for a few weeks. Case 1 emissions can therefore be considered as being temporary and therefore comparison with Regulation 3(3) limit is very conservative**.**

Table 4.1 shows the maximum predicted 99.17th percentile of daily average ground level concentrations for Case 1 emissions exceeds the target of 3.75 μg m^{-3}.

Given that it is considered that Regulation 3(3) should apply to only annual average concentrations and Case 1 emissions are only temporary it is considered the predicted exceedence of the 3% Regulation 3(3) target should be disregarded.

The predictions show that the impacts on air quality of emissions of sulphur dioxide (SO_2) for Case 1 emissions are not of concern to human health because the impacts are, at the most, 5% of the limit values set to protect human health.

5.4 CASE 2 OPERATION

Case 2 operation is predicted to give rise to impacts that are less than Regulation 3(3) limit and not of concern to human health.

5.5 SUMMARY AND CONCLUSIONS

Atmospheric Dispersion Modelling (ADM) Ltd has been commissioned by Adi Associates to undertake dispersion modelling of emissions to atmosphere from the new LNG power station at Delimara, Malta.

The **Phase 1** modelling assessment concluded that emissions to atmosphere at the guaranteed maximum fuel sulphur (S) content of 30 mg Nm^{-3} (273 k, 101.3 kPa) are compliant with Regulation 3(3) and therefore no further mitigation measures are required [(1)].

This report presents the emissions data and predictions for **Phase 2** of the further modelling work which includes modelling of emissions of sulphur dioxide (SO_2) from all the sources which will occur during the post commissioning operation of the facility.

The conclusion of the Phase 2 modelling is that for routine emissions from the facility (Case 2 emissions) the maximum predicted ground level concentrations are compliant with Regulation 3(3).

For Case 1 there are predicted to be localised exceedence of the Regulation 3(3) limit but it is considered, for the following reasons, that this exceedence should be disregarded:

- Applying Regulation 3(3) to a 24 hour average is considered to be conservative.
- The impacts are less than 5% of the ambient air quality limit values set to protect human health and therefore are no of concern to human health.
- Case 1 emissions are for temporary operation of the facility that will occur for no more than a year of possibly only for a few weeks until that storm mooring system is completed.

(1) ADM Ltd (16 September 2016) Sulphur Dioxide (SO_2) Emissions Modelling for the New LNG Plant at Delimara Power Station, Malta Phase 1.