Annex A

Modélisation des émissions atmosphériques

1.1.1 Air Quality Standards (AQS)

The following *Table 2.1* presents in force air quality standards, set by the IFC Environmental, Health, and Safety Guidelines for Air Emissions and Ambient Air Quality published on 2007, which refers to the WHO Air Quality Guidelines; the latter are available at http://www.who.int/en. The table includes only the AQS identified for the pollutants of interest for the Project.

Table 2.1 Air Quality Standards set by the IFC Guidelines for Air Emissions and Ambient Air Quality

Pollutant	Parameter	WHO AQ Guidelines [µg/m3]
NO_2	Annual average	40
	Maximum hourly concentration	200
CO	8h moving average	10000(*)(**)

(*) WHO Air Quality Guidelines for Europe
(**)The maximum daily eight-hour mean concentration will be selected by examining eight-hour running averages, calculated from hourly data and updated each hour. Each eight-hour average calculated will be assigned to the day on which it ends, i.e. the first calculation period for any one day will be the period from 17:00 on the previous day to 01:00 on that day; the last calculation period for any one day will be the period from 16:00 to 24:00 on that day.

2 AIR QUALITY MODELLING

2.1 OVERVIEW

This *Chapter* presents the methodology, input data and results of the quantitative assessment of the potential impacts that may arise as a result of the Project emissions over the Project Area for both scenarios.

A brief overview about the calculation code (CALMET – CALPUFF) adopted for this study is also presented.

2.2 METHODOLOGY AND MODEL INPUT

2.2.1 CALPUFF Modelling System

The air quality simulation study was carried out with the CALPUFF modelling system (version 5.8, adopted and recommended by US-EPA since 29th June 2007 (http://www.epa.gov/scram001/dispersion_prefrec.htm#calpuff).

The chosen modelling system represents the state-of-the–art in Lagrangian puff modelling for assessing impacts of the long-range transport of certain air pollutants. (1)

The CALPUFF modelling system consists of three main components, including a pre-processor and post-processor.

- The meteorological pre-processor CALMET produces the three-dimensional fields for the main meteorological variables, temperature, wind speed and direction, over the simulation domain.
- The processor CALPUFF is a non-steady-state Lagrangian Gaussian puff model containing modules for complex terrain effects, overwater transport, coastal interaction effects, building downwash, wet and dry removal, and simple chemical transformation.(2)
- The post-processor CALPOST statistically analyses CALPUFF output data and produces datasets suitable for further analysis. Post-processed CALPUFF outputs consist of matrices of concentration values. Receptors in the simulation domain can be discrete or gridded. The values calculated at each receptor could be referred to one or more sources.

The results can be processed by any GIS software, creating iso-concentration maps as presented in *Chapter* **2.3** of this study.

[1] Peer Review Of The Calmet/Calpuff Modeling System, Allwine, Dabberdt, Simmons, 1998.

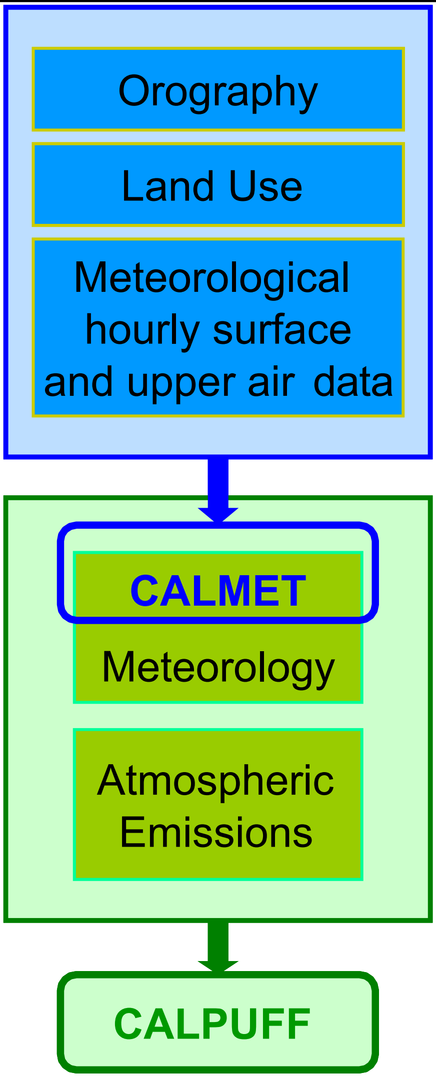
[2] A User's Guide for the CALPUFF Dispersion Model (Version 5), Scire, Strimaitis, Yamartino 2000

The CALPUFF modelling system requires the following input data:

- meteorological variables' surface data and height profile, to build the three-dimensional wind field, with the meteorological pre-processor CALMET;
- source characteristics and emission data, to simulate the pollutants atmospheric dispersion, with CALPUFF.

The following *Figure 2.1* presents a flow chart of the CALPUFF modelling system inputs, while the *Box 2.1* gives a summary of the CALMET CALPUFF and CALPOST characteristics.

Figure 2.1 CALPUFF Modelling System INPUTS



Box 2.1 *Features of the Pre-Processor CALMET, CALPUFF and Post-Processor CALPOST*

CALMET is a diagnostic meteorological pre-processor able to reproduce three-dimensional fields of temperature, wind speed and direction along with two-dimensional fields of other parameters representative of atmospheric turbulence. CALMET is able to simulate wind fields in complex orography domains characterized by different types of land use. The final wind field is obtained through consecutive steps, starting from an initial wind field often derived from geostrophic wind. The wind field is linked to the orography, since the model interpolates the monitoring station values and applies specific algorithms to simulate the interaction between ground and flow lines. The module contains a micro-meteorological module determining thermal and mechanical structures (turbulence) of lower atmospheric layers.
CALPUFF is a hybrid dispersion model (commonly defined 'puff model'). It is a multi-layer and non-steady-state model. It simulates transport, dispersion, transformation and deposition of pollutants, in meteorological conditions varying in space and time. CALPUFF uses the meteorological fields produced by CALMET, but for simple simulations an external steady wind field, with constant values of wind speed and direction over the simulation domain, can be used as input. The module contains different algorithms to simulate different processes, such as: • buildings downwash and stack-tip downwash; • wind vertical shear; • dry and wet deposition; • atmospheric chemical transformations; • complex orography and seaboard.*(In marine coastal areas, CALPUFF considers breeze phenomena in order to model efficiently the Thermal Internal Boundary Layer (TIBL) as in case of coastal sources, the TIBL causes a quick fall of pollutants to the ground.)* Besides, CALPUFF allows the selection of the source geometry (point, linear or areal), improving in this way the accuracy of the emission input. Point sources simulate emissions coming from a small area while areal sources describe a diffuse emission coming from a wider area; emissions from linear sources are distributed along a main direction (i.e. roads).
CALPOST processes CALPUFF outputs producing an outputs' format suitable for further analysis. CALPOST output files can be fed into graphic software to create concentration or deposition maps

2.2.2 *Models Domain*

The CALMET meteorological domain represents the area in which the CALMET pre-processor computes all the meteorology variables (i.e. temp. wind directions wind speed, atmospheric stability) needed to perform the pollutants air dispersion.
The CALMET meteorological simulation domain used in this modelling study, is a 30 km x 30 km area, characterised by a resolution of 250 m. The domain size (900 km^2) has been set according to the emissive source features and dispersion capability.

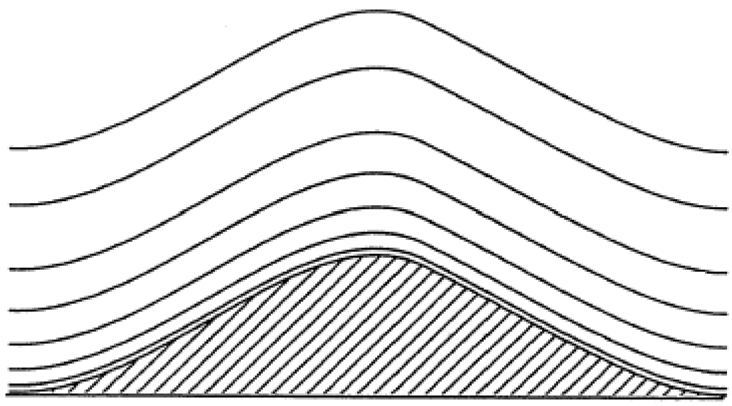
The sampling simulation domain represents the matrix of gridded receptors at whose locations the model CALPUFF calculates the pollutant concentrations. The sampling domain used in this modelling study is a 20 km x 20 km subset of the meteorological domain, with a 250 m resolution.
The central point of each cell in the sampling domain represents a gridded receptor, whose elevation depends on the local orography and is given by the Digital Elevation Model of the area.

The following *Figure 2.2* presents both meteorological and sampling domains used for the present modelling study, highlighting the Power Plant location.

Figure 2.2 Meteorological and Sampling Domains, Power Plant location

The CALMET-CALPUFF models operate in a terrain-following vertical coordinate system; terrain-following vertical coordinates are given by the Cartesian vertical coordinate minus the terrain height (the latter is available from the DEM). The concept of a coordinate system following the terrain is shown in *Figure 2.3.*

Figure 2.3 *Concept of Terrain Following Vertical Coordinate System*



The vertical resolution adopted in the present modelling study consists of 10 terrain following vertical layers, from the ground level up to 3500 m elevation (located at 20 m, 50 m, 100 m, 250 m, 500 m, 750 m, 1000 m, 1500 m, 2000 m, 3500 m from the ground level).

The vertical layers resolution (see *Figure 2.4*) is higher near the surface, (Planetary Boundary Layer), where the transport and the dispersion of air pollutants take place, in order to investigate more accurately these dynamics and their interactions with the local orography.

Figure 2.4 ***Models Vertical Resolution***

The dispersion modelling temporal domain or simulation period is the time period simulated by the model; in the present study the year 2017 was chosen as temporal domain.

2.2.3 *Model Input*

Orography and Land Use

Land Cover data were taken from the Ivory Coast Land Cover database provided by the Food and Agriculture Organisation (FAO) within the geo Network Project, whereas site specific information about regional orography was reproduced using the Shuttle Radar Topography Mission (SRTM) DEM, developed by the US National Aeronautics and Space Administration (NASA).

Meteorological Data

The CALPUFF meteorological input was obtained with the meteorological pre-processor CALMET. The latter requires in input hourly surface data of: wind speed and direction, temperature, atmospheric pressure, relative humidity, cloud cover and ceiling height; and upper air data with a temporal resolution of at least 12 hours for: atmospheric pressure, temperature, wind speed and direction. Upper air data are necessary to characterize the wind regime and the atmosphere diffusive parameters (stability class, mixing height, thermal inversion, etc.), and to produce a three-dimensional simulation.

CALMET input meteorological surface data are typically taken from surface weather stations, if these stations are sufficiently close to the study area to be considered representative of its meteorological conditions. Upper air data are usually acquired from radiosondes surveys, representative for the study area.

For this study, due to the lack of observed surface and upper air data over the above presented meteorological domain, CALMET meteorological input have been taken from MM5 prognostic meteorological model.

MM5 is a widely-used three-dimensional numerical meteorological model which contains non-hydrostatic dynamics, a variety of physics options for parameterising cumulus clouds, microphysics, the planetary boundary layer and atmospheric radiation. MM5 prognostic data is calibrated against any locally monitored data and its use for atmospheric dispersion modelling purposes has been officially recognized by USEPA on the 20th of December 2016 (1).
MM5 is developed by Pennsylvania State University and the U.S. National Centre for Atmospheric Research (NCAR) and raw MM5 output can be converted into a format recognized by CALMET. All the MM5 meteorological data acquired as input for this study have been provided by Lakes Environmental™, a worldwide provider of environmental data (terrain and meteorology), recognized internationally for its technologically advanced air dispersion modelling software [3] (*CALPUFF/MM5 Study Report Final Report June 2001, Earth Tech, Inc.).*

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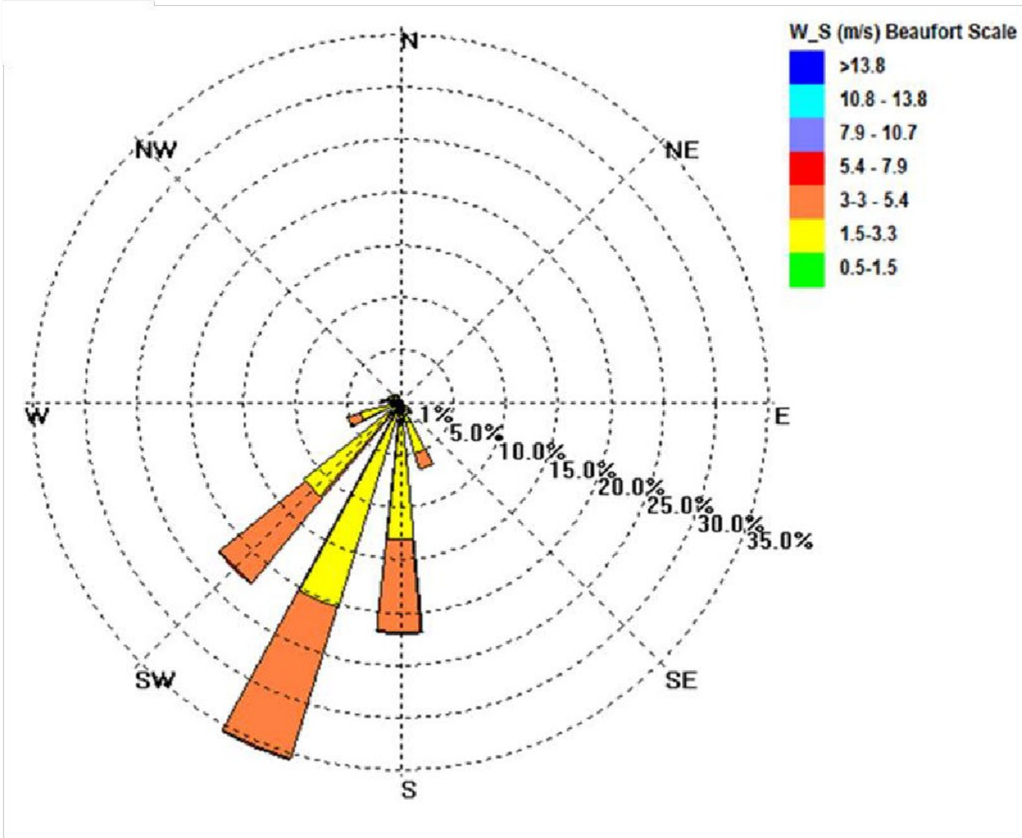
[1] https://www3.epa.gov/ttn/scram/appendix_w/2016/AppendixW_2017.pdf
https://www3.epa.gov/ttn/scram/appendix_w/2016/Appendix_W-WebinarPresentation.pdf

Figure 2.5 presents the wind rose extracted from the CALMET model run performed for the year 2017 at the Project location.

Figure 2.5 Wind Rose extracted from CALMET at Project location



NOTE: according to WMO (World Meteorological Organization) standards, the wind direction plotted in the wind rose is the wind provenance direction.

The wind rose shows that wind regime in the Project area presents a predominant wind direction from S-SW. In terms of wind speeds, moderate winds are prevailing in the area (between 1 and 3.3 m/s). The wind calms (< 0.5 m/s) account for the 2.07% of the year.

Emissions

Two emission scenarios have been investigated in this study:

- Power Plant working on gas, in combined cycle mode;
- Power Plant working on gas, in open cycle mode.

Emissions sources, rate and composition for the above mentioned scenarios are presented in the following part of this section.

Gas Operation– Combined Cycle

This scenario considered the activity of one gas turbine (GT) SIEMENS SGT-4000F in a combined cycle mode.

Table 2.1 presents the geographical location and the characteristics of the Power Plant emission source modelled for this scenario; the gas turbine is labelled GT-CC (Gas Turbine Combined Cycle).

Table 2.1 ***Gas -Combined Cycle : Emission Sources Geographical Location and Characteristics***

Emission Source	X	Y	Stack Height	Stack diameter	Flue Gas Temperature	Flue Gas Velocity
	UTM 30 N [m]		[m]	[m]	[°C]	[m/s]
GT-CC	353760	579965	40	6.7	94	20

The following *Table 2.2* presents the emissions rate and compositions used as input in the modelling study.
The rate and composition of atmospheric emissions produced by the Power Plant have been identified on the base of Project design data.

Table 2.2 ***Gas -Combined Cycle: Emissions Rate and Composition***

Emission Source	Concentration in flue gases* [mg/Nm³]			Emission rate [g/s]		
	NO_x	CO	PM10	NO_x	CO	PM10
GT-CC	52 (1)	19 (2)	Negligible	27.28	9.97	Negligible

** Reference oxygen content [15%]*
(1) 25 ppm dry volume
(2) 15 ppm dry volume

Gas Operation–Open Cycle
This scenario considered the activity of one gas turbine (GT) SIEMENS SGT-4000F in an open cycle mode.

Table 2.3 presents the geographical location and the characteristics of the Power Plant emission source modelled for this scenario; the gas turbine is labelled GT-OC (Gas Turbine Open Cycle).

Table 2.3 ***Gas -Open Cycle: Emission Sources Geographical Location and Characteristics***

Emission Source	X	Y	Stack Height	Stack diameter	Flue Gas Temperature	Flue Gas Velocity
	UTM 30 N [m]		[m]	[m]	[°C]	[m/s]
GT-OC	353761	580003	40	7.1	605.7	40

The following *Table 2.4* presents the emissions rate and compositions used as input in the modelling study.
The rate and composition of atmospheric emissions produced by the Power Plant have been identified on the base of Project design data.

Table 2.4 *Gas -Open Cycle: Emissions Rate and Composition*

Emission Source	Concentration in flue gases* [mg/Nm³]			Emission rate [g/s]		
	NO_x	CO	PM10	NO_x	CO	PM10
GT-OC	52 (1)	19 (2)	Negligible	27.28	9.97	Negligible

** Reference oxygen content [15%]*
(1) 25 ppm dry volume
(2) 15 ppm dry volume

2.2.4 *Assumptions*

This section summarises the assumptions made in the present air dispersion modelling study.

Percentage Oxidation of Nitric Oxide to Nitrogen Dioxide

During the combustion process, two nitrogen based pollutants are generated:

- Nitrogen dioxide (NO_2);
- Nitric oxide (NO).

Together these comprise emissions of oxides of nitrogen. NO_2 is the pollutant of interest from a health perspective as this is considered the most toxic of the two, with NO being largely inert. The emissions from the combined stack will comprise, initially, primarily NO, but through various chemical reactions that will take place in the atmosphere, the NO will be converted to NO_2. Taking the worst case, the assumption is made that all of the NO is converted to NO_2 by the time the emissions reach ground level and therefore human receptors. However, in reality this does not occur and only a proportion of the NO emitted will be converted to NO_2. This is due to the chemical reactions taking time to occur and also 'mopping up' other atmospheric chemicals such as ozone, a process which will limit the reaction rate and therefore limit the generation of NO_2. The conversion of NO to NO_2 is in part a function of the amount of ozone in the ambient air, and the travel time of the plume in the atmosphere (with time, more ozone is entrained into the plume and more conversion can therefore take place).

A number of international agencies have developed guidelines for including in assessments the conversion of NO to NO_2. A summary of the main guidelines are set out below in *Table 6.1*. The ratios set out in Table 2.5 indicate that a wide range of ratios to convert NO to NO_2 are recommended by a variety of country agencies.

Table 2.5 *Recommended NO to NO_2 Conversion Ratio*

Country	Averaging period	Recommended Conversion Ratio
United States	24 hours	80%
	Annual	75%
Germany	24 hours	60%
	Annual	60%
United kingdom	Short term (1 hour)	35%
	Annual	70%
Hong Kong	24 hours	20%
	Annual	20%
Ontario, Canada	24 hours	52%
	Annual	68%

Conservatively the conversion ratios suggested by US Environmental Protection Agency (EPA) have been assumed for long term and short term conversions. These conversion factors (the highest between values reported) have been applied in the results interpretation [4] (*U.S. EPA 40 CFR Part 51*).

Dry and Wet Depositions

The model does not account for dry and wet deposition or photochemical reactions of the pollutants which in reality takes place and would reduce macro pollutants concentrations in the atmosphere. Thus results are overestimating the likely actual contribution of the sources. The approach again is on the safe side of assumptions and gives a conservative picture maximising pollutants modelled concentration values over the sampling domain.

Emission Scenario

- On the base of Project design data, the model assumes that the gaseous fuel does not contain Sulphur;
- The model assumes that the proposed plant operates on a continuous basis i.e. 24 hours per day;
- Pollutant emission rates have been calculated on the base of Project design data.

Air Quality Impacts Assessment Criteria

In absence of detailed and extensive methodologies set by international institutions for the assessment of predicted air quality impacts for future projects, ERM developed a methodology for the classification of the magnitude of air quality impacts. ERM's methodology is based on the IFC General EHS Guidelines for Air Emissions and Ambient Air Quality.

The IFC General EHS Guidelines state:

"*An airshed should be considered as having poor air quality [degraded] if nationally legislated air quality standards or WHO Air Quality Guidelines are exceeded significantly*".

In this context this is interpreted to mean locations where air quality standards are exceeded at all.

The guidelines also state:

"*Projects with significant sources of air emissions, and potential for significant impacts to ambient air quality, should prevent or minimize impacts by ensuring that:*

• *Emissions do not result in pollutant concentrations that reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines, or other internationally recognized sources; and*

• *Emissions do not contribute a significant portion to the attainment of relevant ambient air quality guidelines or standards. As a general rule, this Guideline suggests 25 percent of the applicable air quality standards to allow additional, future sustainable development in the same airshed [i.e. in an undegraded airshed]*".

The IFC guidelines further state:

"*Facilities or Projects located within poor quality airsheds, and within or next to areas established as ecologically sensitive (e.g. national parks), should ensure that any increase in pollution levels is as small as feasible, and amounts to a fraction of the applicable short-term and annual mean air quality guidelines or standards as established in the Project-specific environmental assessment*."

Based on the above, ERM identified the impact assessment criteria summarised in *Table 2.6*, where:

- the Process Contribution (PC): is the impact on air quality arising from the proposed Project emissions only; and

- the Predicted Environmental Concentration (PEC): is the PC added to the existing baseline.

As reported in *Table 2.6*, according to the impact assessment criteria identified the magnitude of impacts depends on:

- whether or not the PC results in air quality standards being exceeded or contribute a substantial proportion of airborne pollutants in the local airshed; and on
- Whether the PEC is above or below the air quality standards (e.g. on whether there is a significant risk of the existing baseline levels to result in air quality guidelines being exceeded).

Table 2.6 ***Assessment Criteria of Magnitude of Impacts on Local Air Quality developed by ERM***

PC as % of AQS	Magnitude
Undegraded Airsheds Where PEC < Air Quality Standards/Guidelines	
<10%	Negligible
10-25%	Small
25-75%	Medium
>75%	Large
Degraded Airsheds, i.e. Where PEC > Air Quality Standards/Guidelines	
<5%	Negligible
5-10%	Small
10-25%	Medium
>25%	Large

Due to the lack of air quality baseline data for the project area, PEC could not be calculated for the present study. However, considering that the project is located in a forest area with no major sources of atmospheric emissions (e.g. industries are absent as well as urban areas), the local airshed was assumed to be undegraded for the purpose of the present impact assessment. As a consequence the impact assessment criteria presented in *Table 2.6* for undegraded airsheds have been used in this study.

2.3 *RESULTS AND CONCLUSION*

The modelling study quantified the Power Plant contribution (process contribution: PC) to local air quality for the Power Plant gas operation under normal operative conditions, for both combined and open cycle modes. CALPUFF calculated NO_2 and CO ground level concentrations induced by the Power Plant activity for both tested scenarios, over an area of 20 km X 20 km, with a 250 m resolution.

The assessment of potential impacts followed the criteria set out in *Section 2.2.4* for undegraded airsheds, based on the comparison of modelled PC against air quality standards set by IFC.

The following part of this Section presents modelling results and the outcome of the impacts assessment for both tested operative scenarios.

2.3.1 *Gas Operation - Combined Cycle: Impact Description and Assessment*

The following *Table 2.7* provides a summary of the results of the performed modelling study for the Gas Operation - Combined Cycle scenario along with the assessment of impacts on local air quality with respect to IFC Air Quality Standards.

Table 2.7 Gas - Combined Cycle: Predicted Concentration Maxima and Magnitude of Impacts on Local Air Quality

Pollutant	Parameter	Modelled concentrations [μg/m³]	IFC AQS [μg/m³]	% of AQS	Impact Magnitude
NO_2	Annual average	0.71	40	1.77%	Negligible
	Maximum hourly concentration	30.82	200	15.41%	Small
CO	8h moving average(*)(**)	4.37	10000(*)(**)	0.04%	Negligible

(*) WHO Air Quality Guidelines for Europe

(**)The maximum daily eight-hour mean concentration will be selected by examining eight-hour running averages, calculated from hourly data and updated each hour. Each eight-hour average calculated will be assigned to the day on which it ends, i.e. the first calculation period for any one day will be the period from 17:00 on the previous day to 01:00 on that day; the last calculation period for any one day will be the period from 16:00 to 24:00 on that day.

The *Table* shows that all modelled pollutants concentrations comply with IFC air quality standards. In particular modelled concentrations are at least one order of magnitude smaller than their respective AQS; thus, according to the impact assessment criteria set for this study, impacts on local air quality due to NO_2 and CO ground level concentrations induced by the activity of the power plant (in combined cycle mode) have been classified as *negligible* and *small*.

The following contour maps have been produced for short and long term NO_2 concentrations:

Figure 2.6 Gas - Combined Cycle: NO2 Annual Average Concentration
Figure 2.7 Gas - Combined Cycle: NO2 Maximum Hourly Concentration

Figure 2.6 Gas - Combined Cycle: NO_2 Annual Average Concentration

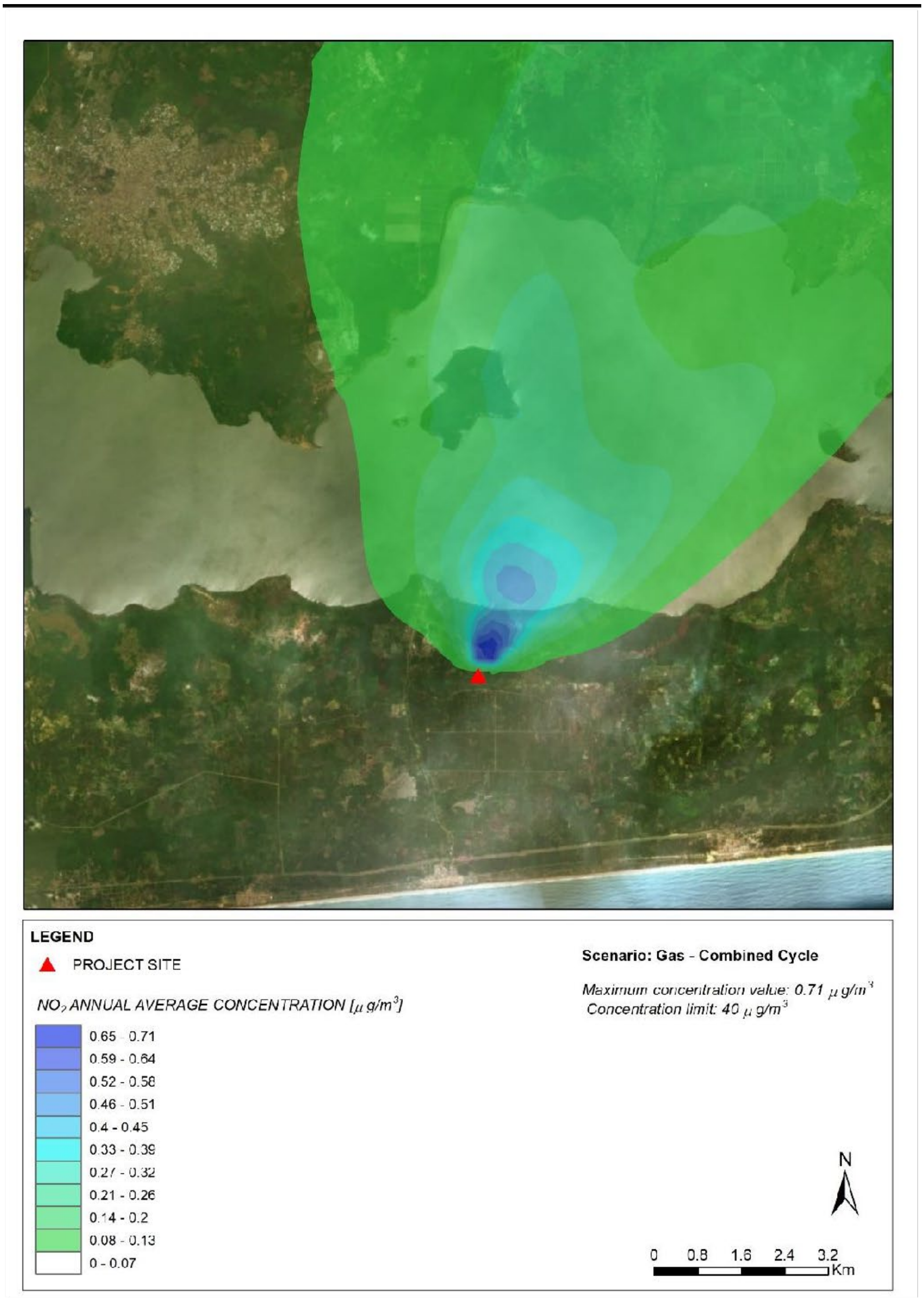
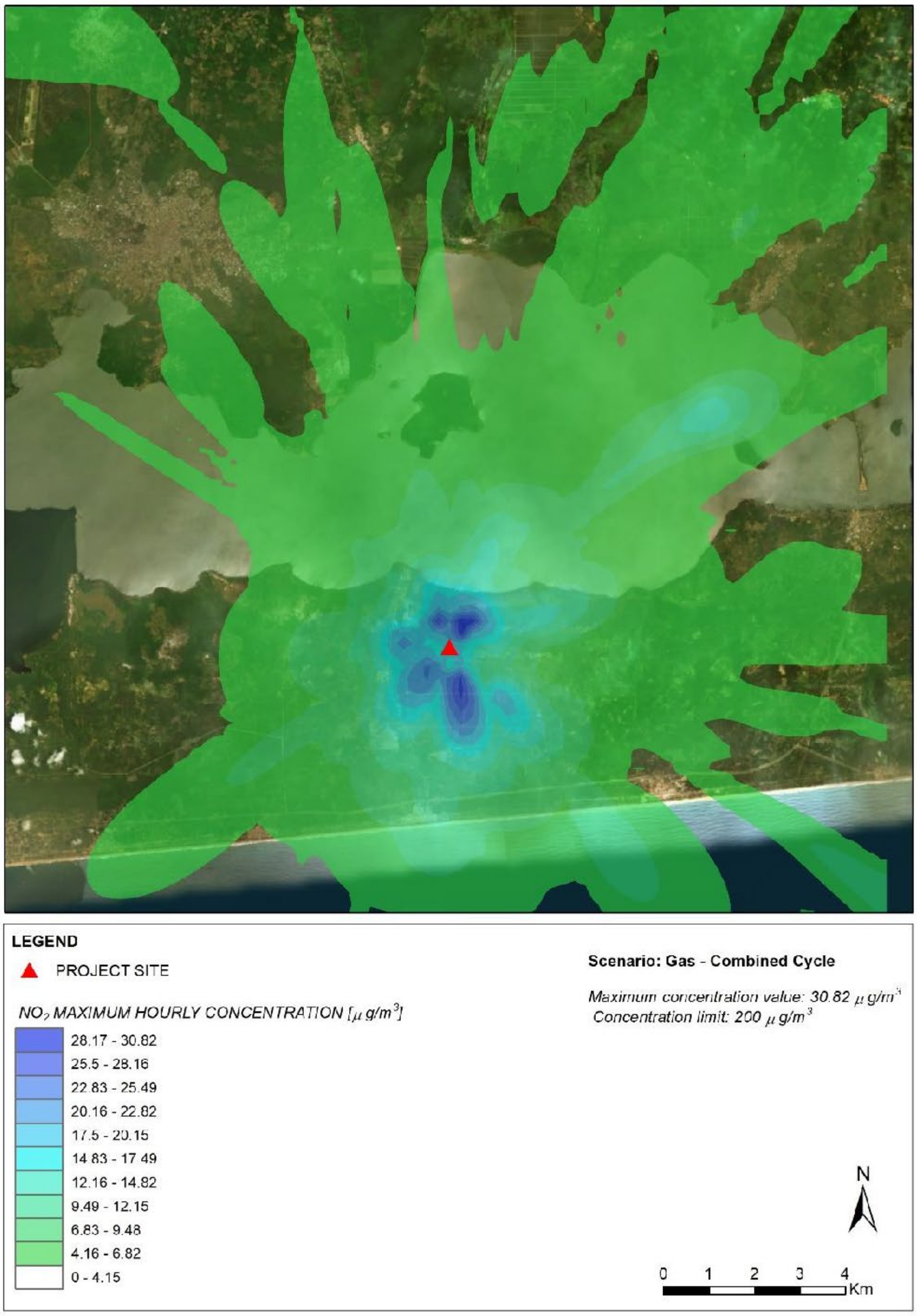


Figure 2.7 Gas - Combined Cycle: NO_2 Maximum Hourly Concentration



The iso-concentration maps show that long term concentration maxima are localised downwind, thus north-east of the Power Plant, in the near proximity of the power plant itself. In particular, the maximum NO_2 annual concentration value is predicted at a distance of approximately 600 m from the Power Plant.

Short term concentration maxima occur both downwind and upwind with respect to the Project site; however, they are confined within 1 km from the Power Plant.

2.3.2 *Gas Operation – Open Cycle: Impact Description and Assessment*

The following Table 2.8 provides a summary of the results of the performed modelling study for the Gas Operation – Open Cycle scenario along with the assessment of impacts on local air quality with respect to IFC Air Quality Standards.

Table 2.8 ***Gas - Open Cycle: Predicted Concentration Maxima and Magnitude of Impacts on Local Air Quality***

Pollutant	Parameter	Modelled concentrations [µg/m³]	IFC AQS [µg/m³]	% of AQS	Impact Magnitude
NO_2	Annual average	0.04	40	0.09%	Negligible
	Maximum hourly concentration	7.79	200	3.89%	Negligible
CO	8h moving average(*)(**)	0.69	10000(*)(**)	0.007%	Negligible

(*) WHO Air Quality Guidelines for Europe
(**)The maximum daily eight-hour mean concentration will be selected by examining eight-hour running averages, calculated from hourly data and updated each hour. Each eight-hour average calculated will be assigned to the day on which it ends, i.e. the first calculation period for any one day will be the period from 17:00 on the previous day to 01:00 on that day; the last calculation period for any one day will be the period from 16:00 to 24:00 on that day.

The *Table* shows that all modelled pollutants concentrations comply with IFC air quality standards. In particular modelled concentrations are at least two order of magnitude smaller than their respective AQS; thus, according to the impact assessment criteria set for this study, impacts on local air quality due to NO_2 and CO ground level concentrations induced by the activity of the power plant (in open cycle mode) have been classified as *negligible*.

In comparison with modelling results obtained for the gas- combined cycle scenario, concentrations are at least one order of magnitude smaller. This is mainly attributable to the higher exit temperature of fumes, bigger diameter of the stack and higher flue gas exit velocity, resulting in increased atmospheric dispersion capabilities of the plume.

The following contour maps have been produced for short and long term NO_2 concentrations:

Figure 2.8 Gas - Open Cycle: NO2 Annual Average Concentration
Figure 2.9 Gas - Open Cycle: NO2 Maximum Hourly Concentration

Figure 2.8 Gas - Open Cycle: NO_2 Annual Average Concentration

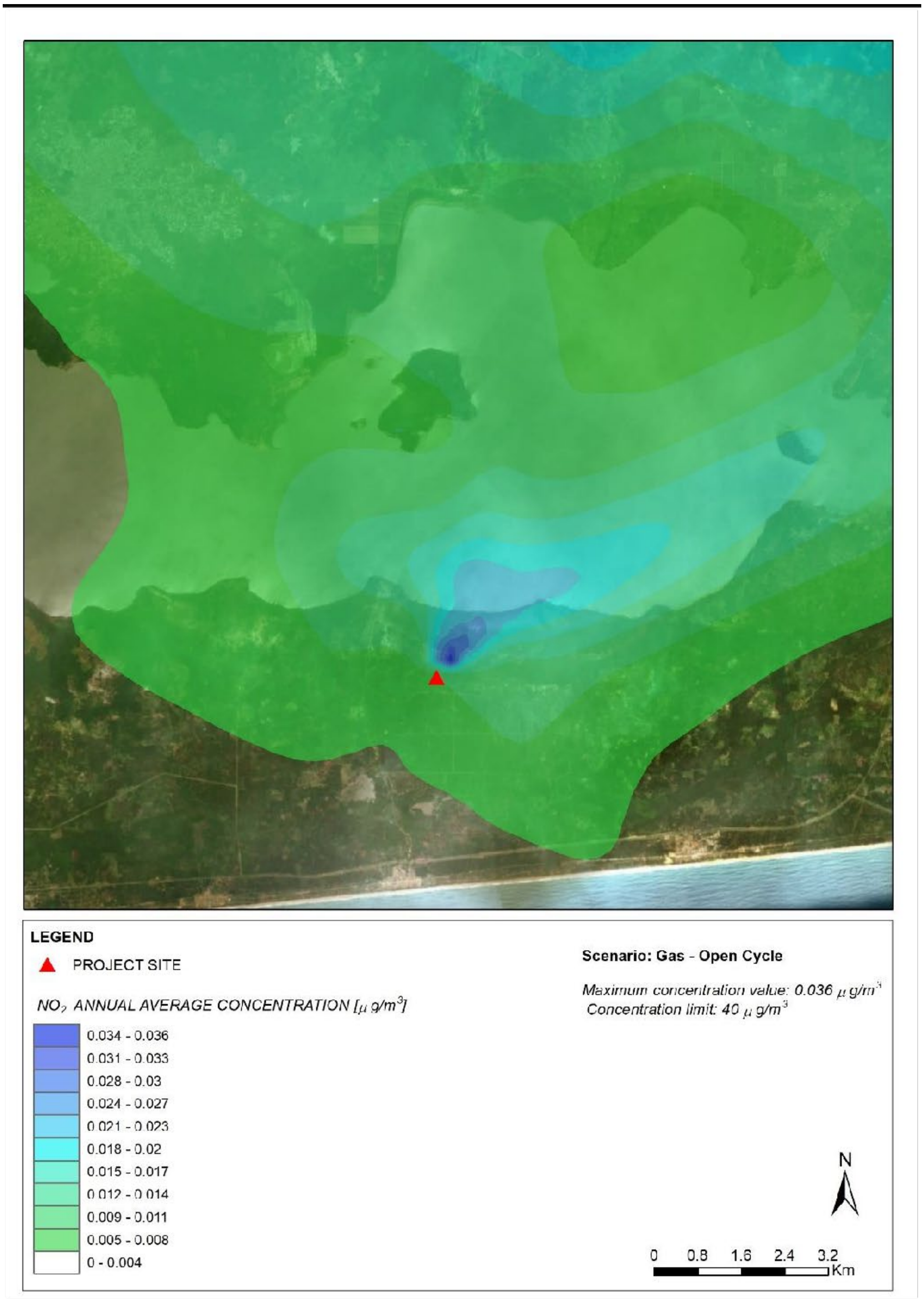
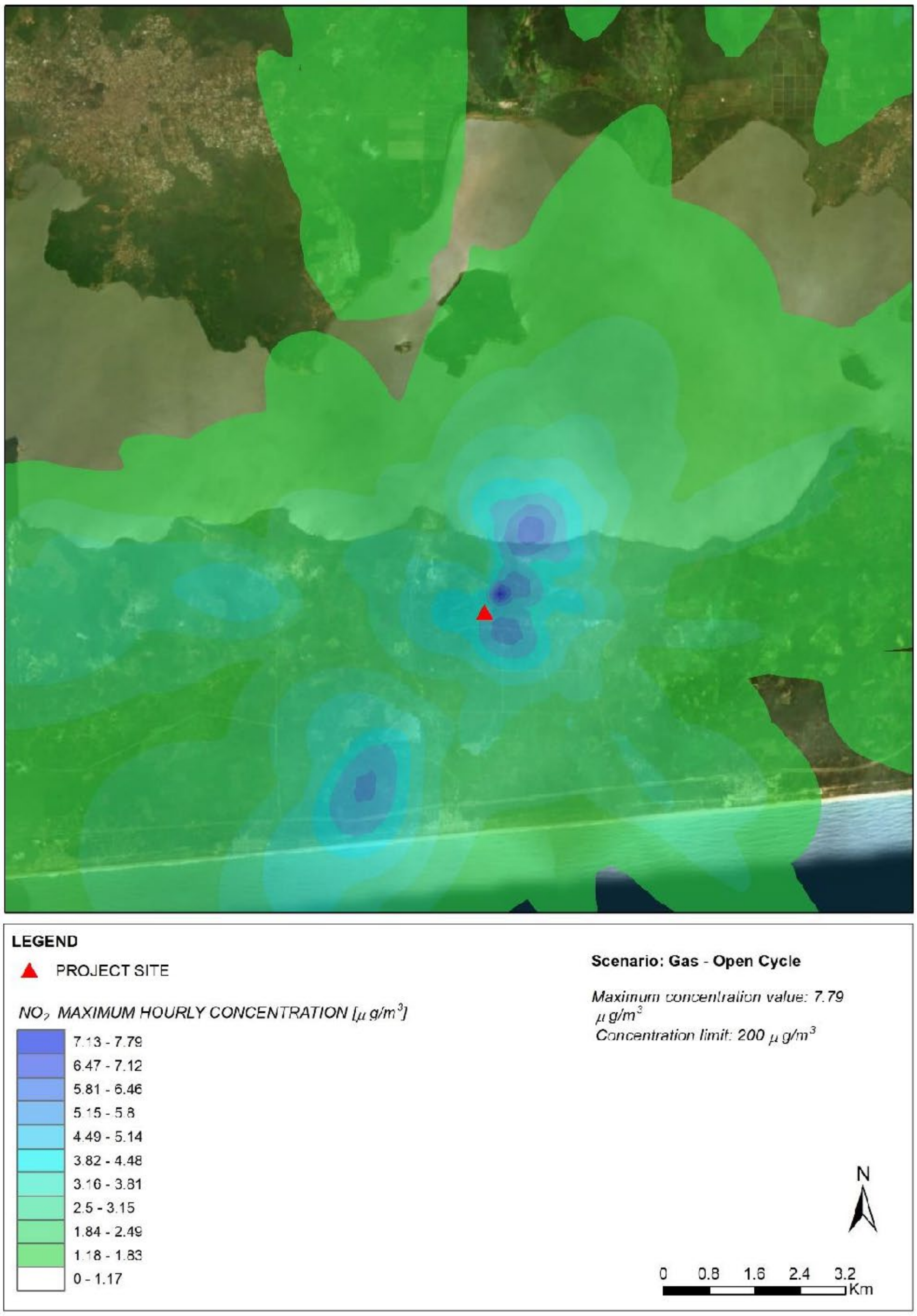


Figure 2.9 Gas - Open Cycle: NO_2 Maximum Hourly Concentration



The above iso-concentration maps show that concentration maxima are localised downwind, thus north-east of the Project location, and in the near proximity of the Power Plant itself.

In particular, the concentration maxima for both long and short term NO_2 concentrations occur at a distance of approximately 450 m north-east of the Power Plant.