IMPACTS OF PROPOSED OIL PRODUCTION ON NEAR SURFACE OZONE CONCENTRATIONS IN THE CASPIAN SEA REGION

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1. INTRODUCTION

The North Caspian Sea in the territorial waters of the Republic of Kazakhstan (RoK) is the site of the largest world-wide oil field discovery in the last thirty years. The production activity associated with extracting these significant oil deposits (33 billion barrels of oil in place of which 11 billion barrels are recoverable) would mean that the full development of this field (the Project) has the potential to become a large-scale industrial emission source of ozone precursors.

To examine the potential impacts, a project team comprised primarily of Environmental Resources Management (ERM), RWDI AIR Inc. (RWDI) and the University of North Carolina at Chapel Hill (UNC) were commissioned to model the peak emission period of the Project to quantify predicted ozone concentrations (both with and without Project contributions).

2. OZONE EVALUATION CRITERIA

A range of international (World Health Organization (WHO), United States (US) and European Union (EU)) and national (RoK) air quality standards and guidelines exist for ozone, ranging from a 20 minute to a 5 year period. The model is not capable of modelling averaging periods <one hour and modelling periods longer than 3 months was considered excessive. Hourly modelling results were assumed to be representative of the 20 minute period and the 3 month EU long-term objective considered to be indicative of the WHO 6 month guideline. The different ozone evaluation criteria used to assess Project compliance is provided in Table 1.

Period	Criterion	Metric	Source
20 min	160 $\mu g/m^3$	Two to four 20 to 30 min samples, any time of day	RoK MPC for residential areas
1 hr	180 $\mu g/m^3$	Average	EU Information threshold
	240 $\mu g/m^3$	Average	EU Alert threshold
8 hrs	100 $\mu g/m^3$	Max 8-hour average per day	WHO Guideline (human health)
	120 $\mu g/m^3$	Max 8-hour average per day, not to be exceeded on >25 days per calendar year, averaged over 3 yrs.	EU Target value for the protection of human health
	120 $\mu g/m^3$	Max 8-hour average per day, within a calendar year	EU Long-term objective for the protection of human health
	0.075 ppm *(150 $\mu g/m^3$)*	Max 8-hour avg per day to determine the 4th highest per year. Annual values then averaged over 3 yrs	US EPA National Ambient Air Quality Standard (NAAQS)
	160 $\mu g/m^3$	Maximum 8-hour average per day	WHO Interim target
	240 $\mu g/m^3$	Maximum 8-hour average per day	WHO High level
24 hrs	30 $\mu g/m^3$	Average of the 20- to 30-minute samples taken daily	RoK MPC for residential areas
5 days	0.2 ppm•h^{-1} *(400 $\mu g/m^3$•h)*	AOT40, 1-h daylight when VP deficit < 1.5 kPa	WHO Critical level for visible damage to crops - humid air
	0.5 ppm•h^{-1} *(1000 $\mu g/m^3$•h)*	AOT40, 1-h daylight when VP deficit > 1.5 kPa	WHO Critical level for visible damage to crops - dry air
3 mon	3 ppm•h^{-1} *(6000 $\mu g/m^3$•h)*	AOT40, 1-h daylight from May to July	WHO, Critical level for protection of ag. crop yield loss 5%
	3 ppm•h^{-1} *(6000 $\mu g/m^3$•h)*	AOT40, 1-h daylight from May to July	WHO Critical level for protection semi-natural veg'n
	6000 $\mu g/m^3$•h^{-1}	AOT40, 1-h daylight from May to July	EU Long-term objective for the protection of vegetation
	18 000 $\mu g/m^3$•h^{-1}	AOT40, 1-h daylight from May to July, average 5 yrs	EU Target value for the protection of vegetation
6 mon	10 ppm•h^{-1} *(20000 $\mu g/m^3$•h)*	AOT40, 1-h daylight from April to September	WHO, Critical level for the protection of forest trees

Table 1. Ozone Assessment Criteria

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3. MODEL DOMAINS

As shown in Figure 1, CMAQ was configured with a 36 km resolution parent domain (70 x 74 cells), a 12 km resolution intermediate nested domain (135 x 145 cells), and an inner 4 km resolution domain (118 x 118 cells) with grid dimensions and positions chosen to provide the highest model resolution in the area nearest the Project sources.

The WRF and CMAQ models used 33 vertical layers from the surface up to 100 mb with narrower bands closer to ground to better capture transport and mixing within the atmospheric boundary layer.

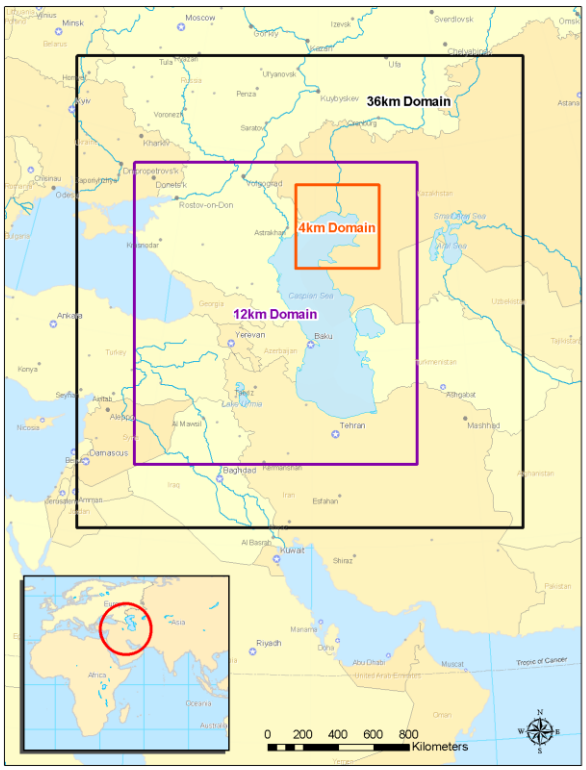

Figure 1. CMAQ Modelling Domains.

4. WRF METEOROLOGICAL MODEL

The Weather Research and Forecast model (WRF) version 3.1 was initialized using Global Forecast System (GFS) 0.5 degree reanalysis meteorological fields obtained from the National Centre for Atmospheric Research (NCAR) for the 2007 base year. This year was selected because it was the year for which the emission inventory for the much of the Middle East had already been compiled in support of similar modelling projects in the region.

Surface meteorological data (daily average temperature, peak daily temperature, and wind speed) from the Project area were compared across 2005 to 2009 for the June to August period. This comparison showed that during the 3 month summer period modelled, both the daily average and daily maximum temperatures in 2007 were slightly greater (+2% to +3%) than the 5-year average and daily average wind speeds were slightly lower (about 10%) in 2007 than the 5-year average. These factors were perceived as making 2007 a good, slightly more conservative choice for ozone modelling as higher temperatures and lower wind speeds generally result in greater ozone formation potential.

The WRF model outputs were post-processed using the Meteorology-Chemistry Interface Processor (MCIP) version 3.5.1 without collapsing vertical layers to prepare SMOKE and CMMAQ-ready inputs.

5. EMISSION INPUTS

5.1 Biogenics

Biogenic emissions were modelled using the Model of Emissions of Gases and Aerosols from Nature (MEGAN) biogenic emissions system.

5.2 Non-Project Anthropogenic Emissions

Emissions for anthropogenic sources were obtained from global, regional and local databases. Where overlaps occurred, the datasets that best matched the time period being modelled and had the highest spatial resolution were selected. The primary databases used included:

- the “Climate Change and Impact Research: Mediterranean Environment (CIRCE)” year 2005 country-level inventory;
- the Emissions Data for Global Atmospheric Research (EDGAR) 3.2 fast track year 2000 country-level inventory; and
- the European Monitoring and Evaluation Program (EMEP) year 2006 50 km gridded inventory.

The CIRCE, EDGAR and EMEP inventories represent emissions as vertical air column totals and hence require the application of vertical distribution profiles for inventory sectors such as energy generation and manufacturing.

The year 2006, one degree (approximately 110 km resolution) gridded, 8 day averaged Global

Fire Emissions Database (GFED) version 2 was used for biomass burning emissions and the University of Delaware 2001 gridded commercial shipping inventory at 0.1 degree (approximately 11 km) resolution was used to estimate emissions from non-Project marine sources.

Figures 2 and 3 show gridded, non-Project NOx and VOC emissions (respectively) for a single representative day and time for the 36 km grid. Both NO_x and VOC gridded emissions peak at around 70 moles per second. This is equivalent to about 83,900 tonnes per year of NO_x, assuming 50% NO and 50% NO_2; and, about 92,700 tonnes per year of VOCs (per maximum grid square), assuming a rough estimate of 50% isoprene and 50% methane.

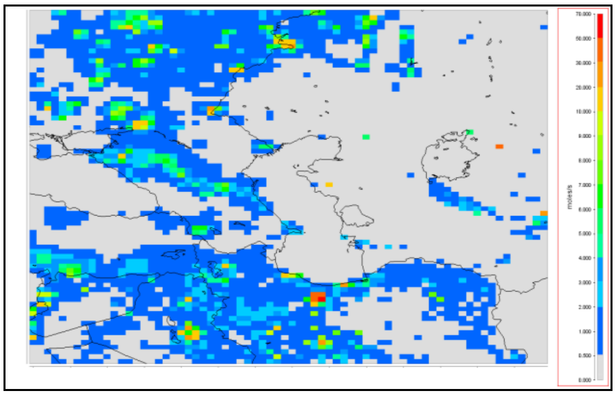

Figure 2. Gridded NO_x Emissions.

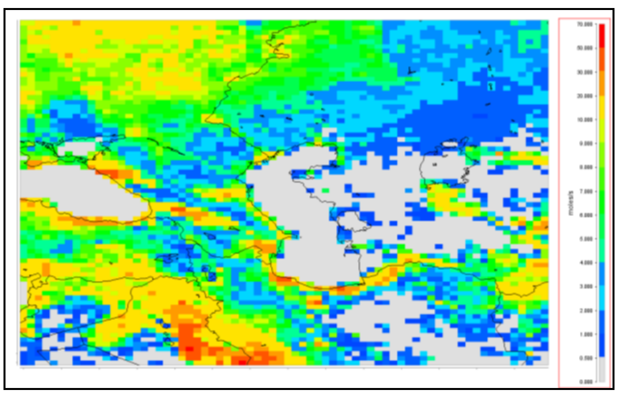

Figure 3. Gridded VOC Emissions.

5.3 Project Emissions

Air emissions from Project operations result primarily from combustion sources, flaring and fugitive losses. The following emission source types were included in the inventory:

- Gas Turbines (onshore and offshore);
- Flares (onshore and offshore);
- Incinerator (onshore);
- Heaters (onshore);
- Steam Generation (onshore);
- Thermal Oxidizers (onshore);
- Flared Storage Tank Emissions (onshore);
- Fugitive Leak Losses (onshore and offshore);
- Marine Transport Emissions;
- Land Transport Emissions; and,
- Railway Transport Emissions.

Flares typically occur as a result of a malfunction or maintenance activities, making it impractical to predict the timing of their occurrence. Randomly assigning flare events to certain hours may not have placed the events at times when the conditions for ozone formation were not optimal. Instead, it was decided to spread the total emissions from these events equally over the modelled period. Once the initial modelling was done, discrete flaring events were modelled during peak ozone events (caused by other emissions) to determine if flaring could increase predicted ground level ozone.

Emissions sources that do not typically operate during the peak ozone season (e.g., winter vessels, emergency generators, etc.) were omitted.

6. MODEL CONFIGURATION

Emissions data were processed using version 2.6 of the SMOKE processing system. To capture atmospheric conditions at the boundaries of the study region (e.g., Western Europe, Russia, central Asia, and western Asia), Initial Conditions (ICON) and Boundary Conditions (BCON) were derived from GEOS-Chem global chemistry model simulations obtained from Harvard University, and adapted for input to CMAQ using UNC's GEOS2CMAQ

Photochemical modelling was conducted using version 4.7 of the CMAQ modelling system with the CB05 chemical solver (CB05-AE4-AQ mechanism) and the inline photolysis module.

7. RESULTS

Key results are presented in Table 2. Figures 4a,b and 5a,b show example results for the 1-hr and 3-month AOT averaging periods, respectively. The figures represent a composite of the results of the 4 km and 12 km grids.

Table 2 focuses on results from the inner domain only. Total predicted ozone concentrations and AOT40 values are sometimes higher outside the 4 km grid (Figure 4) but these maxima are not affected by Project contributions.

Period	Assessment Criterion: Value	Assessment Criterion: Source	Assessment Criterion: Applicability	Maximum Value (2): Over Land and Sea	Maximum Value (2): Over Land Only	Maximum Project Contribution: Over Land and Sea	Maximum Project Contribution: Over Land Only	Criterion Exceeded?(2)
20 to 30 minutes(1)	160 $\mu g/m^3$	RoK MPC	Over land only (residential areas)	N/A	143 $\mu g/m^3$	Criterion not applicable over sea	18.2 $\mu g/m^3$	No
1 hour	180 $\mu g/m^3$	EU Information threshold	Over Land and Sea	147 $\mu g/m^3$	143 $\mu g/m^3$	31.3 $\mu g/m^3$	18.2 $\mu g/m^3$	No
	240 $\mu g/m^3$	EU Alert threshold	Over Land and Sea					No
8 hours	100 $\mu g/m^3$	WHO Guideline (human health)	Over Land and Sea	**127** $\mu g/m^3$	**124** $\mu g/m^3$	23.4 $\mu g/m^3$	11.9 $\mu g/m^3$	**Yes**
	120 $\mu g/m^3$	EU Target value (human health)	Over Land and Sea					No(3)
	120 $\mu g/m^3$	EU Long-term objective (human health)	Over Land and Sea					**Yes**
	150 $\mu g/m^3$	US EPA NAAQ	Over Land and Sea					No
	160 $\mu g/m^3$	WHO Interim target	Over Land and Sea					No
	240 $\mu g/m^3$	WHO High level	Over Land and Sea					No
24 hours	30 $\mu g/m^3$	RoK MPC	Over land only (residential areas)	**112** $\mu g/m^3$	**110** $\mu g/m^3$	9.55 $\mu g/m^3$	5.02 $\mu g/m^3$	**Yes**
5 days	400 $\mu g/m^3 \cdot h$(4)	WHO Critical level visible damage to crops (humid air) (4)	Over land only (crops only) (4)	N/A	**1185** $\mu g/m^3 \cdot h$	N/A	157 $\mu g/m^3 \cdot h$	N/A(4)
	1000 $\mu g/m^3 \cdot h$	WHO Critical level visible damage to crops (dry air)	Over land only (crops only)					**Yes**
3 months	6000 $\mu g/m^3 \cdot h$	WHO Critical level for 5% crop damage/ WHO Critical level for semi-natural vegetation/EU Long-term objective (vegetation)	Over land only	N/A	**6914** $\mu g/m^3 \cdot h$	N/A	1914 $\mu g/m^3 \cdot h$	**Yes**
	18000 $\mu g/m^3 \cdot h$	EU Target value for the protection of vegetation	Over land only					No

Table 2. Model Results
(1) Minimum modelling period is 1 hour.
(2) Bold indicates a criterion is exceeded.
(3) The maximum value is >120µg/m^3 threshold but the EU Target allows the threshold to be exceeded up to 25 times per year. The results predicted that is >120µg/m^3 threshold is exceeded on only 8 occasions within the modelling period and therefore the standard is not likely to be exceeded over the course of a year.
(4) A review of the meteorological conditions when 40 ppb is exceeded within the 4 km grid indicated that exceedances occur exclusively during dry conditions.

The widespread exceedance of various ozone assessment criteria suggests that excess ozone formation is an issue for the entire region, regardless of the presence of the Project. The Project contributions are primarily confined to the northern portion of the Caspian Sea, and are largest over the Sea itself. The largest relative Project contributions to predicted exceedances occur for the longer averaging periods (i.e., the 3-month summation period).

7.1 NO_x / VOC Sensitivity

To assess Project contributions further and their sensitivity to NO_x and / or VOC emissions the model was re-run for a peak ozone day (30 July) using the following simple scenarios with alterations made to Project emissions only:

- NOx +50% with VOC unchanged;
- NOx -50% with VOC unchanged;
- VOC +50% with NOx unchanged; and,
- VOC -50% with NOx unchanged.

As anticipated (results not shown), the northern Caspian Sea is in a NO_x limited regime where varying NO_x emissions had a significant effect on the ozone concentrations in the vicinity and downwind of the Project and changes in VOC had little impact on predicted concentrations.

7.2 Discrete Flaring Events

In addition to the NO_x and VOC sensitivity tests, a series of simulations were performed to assess impacts associated with peak, short-duration offshore flaring activities. This modelling was conducted over the 4 km domain only and for a discrete peak ozone period that extended from 29 to 31 July.

Figure 4a. Peak modelled 1-hr ozone.

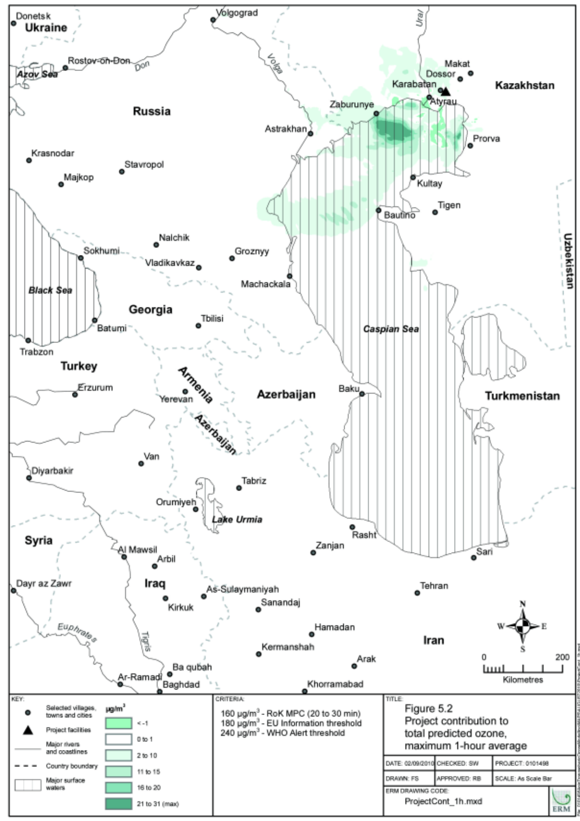

Figure 4b. Peak 1-hr ozone sources (Project Sources).

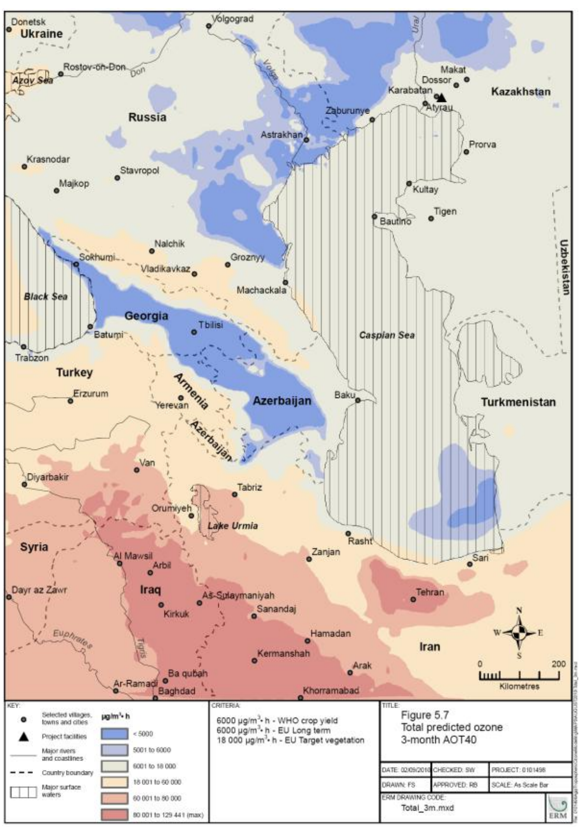

Figure 5a. Modelled 3-month AOT40.

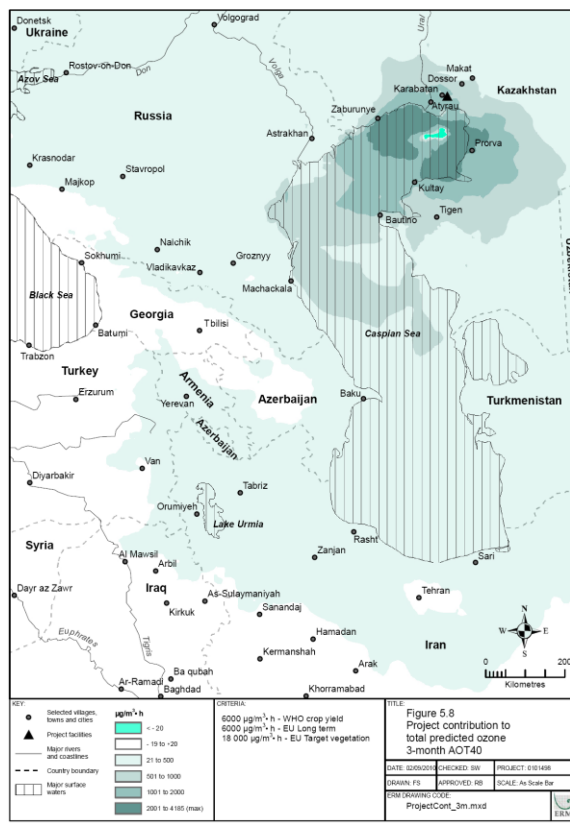

Figure 5b. Modelled 3-month AOT40 (Project Sources).

As shown in Figure 6, for the 1-hour averaging period this discrete flaring event resulted in a predicted increase of 16 μg/m^3 in the over-land maximum ozone concentration (without the flaring event the maximum over-land ozone concentration was 143 μg/m^3; hence the flaring event resulted in a 11% increase in the maximum 1-hour ozone concentration).

However, the domain-wide maximum increase in hourly ozone concentration was about 100 μg/m^3 but this occurs over water, about 4 hours following the discrete flaring event. Changes to on-land ozone concentrations are not predicted to be seen until 6 hours after the release, by which time the net additive contribution has decreased to about 16 μg/m^3 or less (Figure 6).

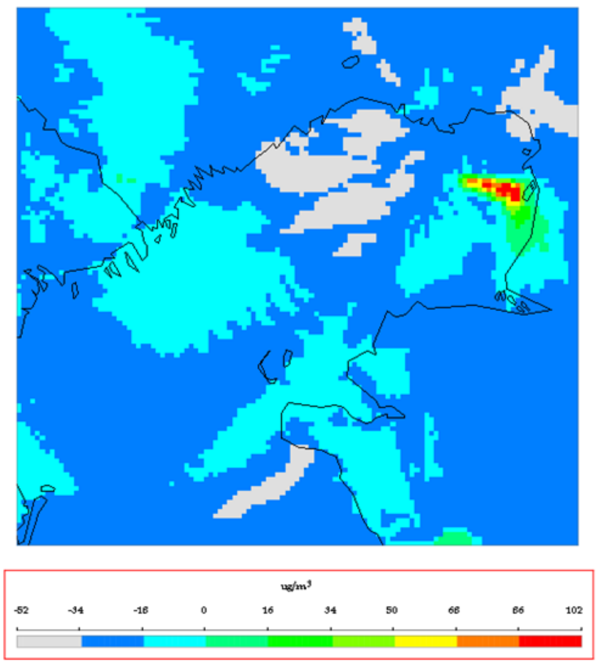

Figure 6. Peak one-hour ozone contributions from Project discrete flaring event (four hours after actual release).

8. CONCLUSIONS

Based on the predictions across the modelled region, it is clear that ozone is potentially a problem for human health and some vegetation in the region, without the additional emissions associated with the oil and gas production activities of the Project. The Project itself has a relatively modest impact on ozone concentrations. Its non-negligible contributions are primarily confined to the northern portion of the Caspian Sea, and are greatest over the sea where there is limited scope for ozone to have harmful effects.

The largest relative Project contributions to predicted exceedances occur for the longer assessment periods and, in particular, the 3-month period of accumulated exposure relevant for vegetation. If the Project emissions were to be reduced, then it is likely that the Project contributions to ozone concentrations would also decrease. However, because of the complex nature of ozone chemistry, the magnitude of this change could only be estimated by further modelling.

The NO_x emissions assumed in the modelling are very much an upper estimate, based on conservative assumptions about the technology of gas turbines specified in the Project design. In fact, by making some reasonable assumptions about the type of turbines to be deployed, the Project NO_x emissions could be about 50% lower than those modelled.

Although it is not possible to quantify the expected reduction in ozone concentrations that would be achieved by using gas turbines with lower emissions without further modelling, the modelling shows that ozone generation in the region is more sensitive to emissions of NO_x than VOCs. Reducing emissions of NO_x from the Project would therefore be an effective way of reducing the Project's contribution to ozone formation in the region.

Beyond consideration of the Project and its rather small impact on ozone concentrations, this modelling study has demonstrated that there is significant potential for emissions in the region to cause ozone concentrations that are in excess of air quality standards and guidelines. Increased economic development in countries around the Caspian Sea, including thorough oil and gas production, might exacerbate this existing impact if uncontrolled.

9. ACKNOWLEDGEMENTS

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