GROUND LEVEL OZONE POLLUTION

DEPARTMENT OF ENVIRONMENT
Ministry of Natural Resources and Environment
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1 Introduction

Ozone in the stratosphere is an important component of the atmosphere that protects the earth from harmful ultraviolet (UV) rays. At ground level however, ozone is a harmful pollutant. Ground level ozone is one of the pollutants that have been linked to health and mortality risks. Besides human health, ozone also adversely affects plants and thereby decreases crop yields. Its strong oxidising property damages materials such as fabrics and rubber based products and hence shortens their life span. It is also a greenhouse gas. Figure 1.1 illustrates some of the effect of ground level ozone pollution.

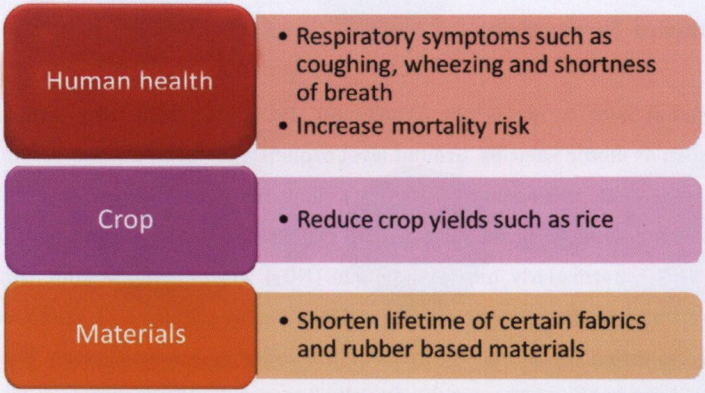

Figure 1.1 Adverse effects of ozone exposure

The rapid growth of the industrial sector and increasing urbanization in Malaysia have contributed to the deterioration of air quality due to emission of pollutant gasses via point sources such as power plants and non-point sources such as motor vehicles. Ground level or ambient ozone standards have been set in order to protect public health and welfare. Table 1.1 presents the ambient ozone standard adopted by Malaysia. Although the proposed guideline may occasionally be exceeded due to natural sources, the most likely causes are expected to be anthropogenic.

Table 1.1 Ozone standards based on the two interim stages of the Malaysian Ambient Air Quality Standard and the new, more stringent target for 2020.

Year	1-hr average		8-hr average	
	(μg/m3)	PPM	(μg/m3)	PPM
2015 (Interim target 1)	200	0.1	120	0.06
2018 (Interim target 2)	200	0.1	120	0.06
2020	180	0.09	100	0.05

2 Ozone formation

Ground level ozone is not a pollutant directly emitted from anthropogenic sources such as motor vehicles. Ground level ozone(O_3) is formed when atomic oxygen (O) combines with molecular oxygen (O_2). This reaction however is preceded by reactions that contribute to the formation of the atomic oxygen. Reactions of oxides of nitrogen (NO_x), particularly nitrogen dioxide (NO_2), and volatile organic compounds (VOC) contribute to the formation of ground level ozone (Figure 1.2). Compounds that contribute to ground level ozone formation are called ozone precursors. The ground level ozone formed further reacts with other species in the atmosphere due to its reactivity. These reactions destroy or create more ground level ozone depending on the chemical composition of species present. Carbon monoxide for example aids in the formation of ground level ozone.

The physical environment is also an important factor as the pathway for ground level ozone formation requires the presence of sunlight, or specifically ultraviolet light. Hence, sunny days with cloudless skies are more conducive to ground level ozone formation. Ground level ozone concentration is also influenced by the monsoon seasons. Besides cloudiness and rainfall pattern, seasonal wind direction also influences the distribution of ground level ozone via short and long range transport of ozone and its precursors.

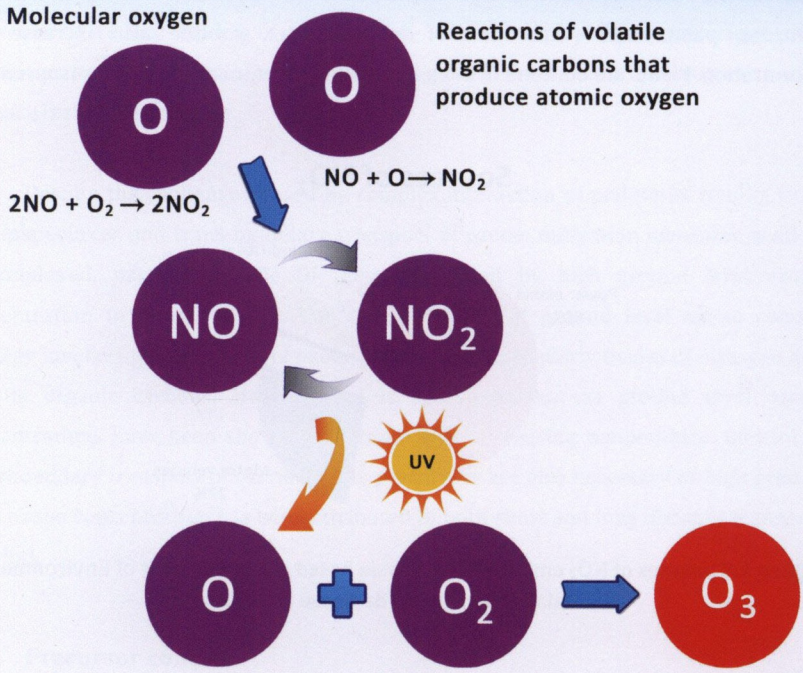

Figure 1.2 Formation of ground level ozone via oxides of nitrogen and volatile organic carbon emitted from anthropogenic and biogenic sources contribute to ozone formation in the presence of sunlight.

3 Sources of ozone precursors

The main sources for nitrogen dioxide are shown in Figure 1.3. The largest contributors to nitrogen dioxide emission in Malaysia are power plants and motor vehicles. Nitrogen dioxide (NO_2) is formed when oxygen in the air reacts with nitrogen oxide (NO), a gas that is usually released during high temperature combustion processes.

Sources of volatile organic carbon also include vehicular and power plant emissions. Another important source is the use of solvents in industrial processes. Pesticides, paints and evaporation of fuel such as gasoline also increase its concentration. Plants are emitters of biogenic volatile organic carbon such as isoprene.

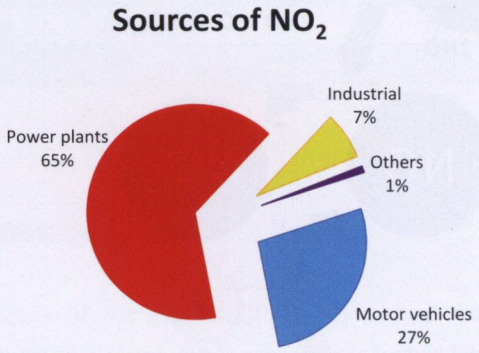

Figure 1.3 Sources of NO_2 emission in Malaysia based on Department of Environment Malaysia emissions database (2014)

4 Ozone mitigation

Strategies for reducing ground level ozone concentration are less straight forward compared to most other pollutants that are directly emitted from its source. The complexity of the photochemical reactions that form ground level ozone poses a challenge to decision makers as regulating emission of a single precursor can potentially increase ground level ozone concentration. For example, nitrogen oxide (NO) which forms the ozone precursor nitrogen dioxide (NO_2) can also contribute to ground level ozone destruction. Similar to a titration reaction between an acid and a base which forms salt and water, NO acts as a 'titrator' of ground level ozone by reacting with it and forming NO_2 and molecular oxygen. The effect of this behaviour of NO can be observed at highly urbanized areas. Ground level ozone concentration is typically higher during

weekends than weekdays as there are fewer cars on the road on weekends. The lower NO concentration from vehicular emission reduces ozone destruction. Hence, if only measures to reduce oxides of nitrogen are implemented without reducing other precursors such as volatile organic carbons, ground level ozone concentration may increase instead of decrease.

Despite the challenges posed by complex interaction of pollutants coming from multiple sources and trans-boundary transport of ozone, mitigation measures need to be employed, particularly due to the risks posed by high ground level ozone concentration to human health. The primary mode of ground level ozone control strategy involves the reduction of ozone precursors, particularly oxides of nitrogen and volatile organic carbons. Heat control is also important as ground level ozone concentrations have been shown to increase with increasing temperature. Control of transboundary transport of ozone and its precursors are also necessary as high ground level ozone concentration has been attributed to both short and long distance transport by wind.

4.1 Precursor control

The formation of ground level ozone from its precursors is a non-linear reaction. In other words, increasing the concentration of the precursor does not necessarily cause a comparable increase in ground level ozone concentration. The relative concentration of different precursor species present also influences the observed ground level ozone concentrations.

In a condition called VOC limited regime, increasing the concentration of volatile organic carbons (VOCs) increase ground level ozone concentrations but the increase in oxides of nitrogen (NO_x) reduces ground level ozone. Urban areas are usually VOC limited and hence mitigation strategies to reduce the concentration of NO_x alone can result in increased ground level ozone concentration.

In a NO_x limited regime, increase in NO_x increases ozone but changes in the concentration of volatile organic carbon concentration does not change ground level ozone concentration much. In rural areas where emission of volatile organic carbons are high, control measures to reduce oxides of nitrogen would be more effective as these areas are usually NOx limited i.e. ground level ozone formation is limited by availability of the oxides of nitrogen.

Identification of ground level ozone production regimes before suggesting any ozone reduction strategies is important due to the sensitivity of ground level ozone photochemical processes to different VOC and NO_x concentrations. Unjustified strategies may in turn result in increased ozone. Typically in busy areas such as the city centers where the concentration of NO as a titrator of ground level ozone is high, VOC needs to be reduced. On the other hand, in the residential areas, where NO_x and VOCs are low, the concentrations of both pollutants need to be controlled. In the rural area where there is possibility of high VOCs especially from biogenic sources, the concentration of NO_x needs to be controlled. Currently a comprehensive database on VOC observation and emission by source category is lacking. Observational data on VOC distribution would help policy makers to make informed decision on more effective abatement strategies.

In the Clean Air Action Plan (DOE, 2010), a review of existing emission standards for the industry is stated and as such Clean Air Regulation 2014 was introduced to further enhance the plan strategy in improving the air quality status in the country. By having better fuel quality standard in our country such as EURO 4M and EURO 5 the vehicle owners could take the opportunity to upgrade their old technology vehicles to the latest or lowest emission engines with better fuel economy, like EURO 4, EURO 5 or EURO 6 engines.

4.2 Control on transboundary ground level ozone

Ground level ozone precursors may be transported over long distances e.g. regional, continental, resulting in ozone formation far from its source. Each year Malaysia experiences air pollution due to the air mass plume transporting from areas prone to biomass burning. Therefore, it is important to consider the reduction of precursors by a trade-off between local and transboundary sources. Although it is difficult to control transboundary ozone pollution, current discussions on regional improvement of air quality should be continued to reduce transboundary pollution.

4.3 Heat control

Ground level ozone mitigation plan is best implemented in corroboration with existing urban heat island mitigation strategies as surface heating enhances ground level ozone production. Plantation and greening in urban areas can ideally reduce temperatures in urban heat islands. In addition, the introduction of a good number of watersheds in the urban areas would reduce ambient temperature.

Some plants however, emit large amounts of biogenic volatile organic carbons (VOCs) with high ozone formation potential. Hence, there is a need for an additional selection process based on VOC emission potential of plants when planning urban landscaping. Currently there is limited information available on Malaysian plant species particularly those used in landscaping.

Global increase in temperature should also be addressed as it will also contribute to increased local and global ozone concentrations.

4.4 Research and development for ground level ozone mitigation

Understanding the VOC-NO_x-ozone relationship is crucial to develop a comprehensive mitigation strategy. Monitoring the pollutants is necessary for a better understanding of ozone photochemistry and to assess the success of mitigation measures. There is also a need for improving ground level ozone forecasts to improve understanding of the complex ozone photochemistry and interaction in tropical conditions.

Monitoring and research on the characterization of anthropogenic and biogenic VOC, and improvement of forecasts to allow for a comprehensive framework and identification of specific mitigations measures for reducing ambient ozone concentration in Malaysia should be strengthened. Assessment of human health and crop yield losses in the tropics due to ambient ground level ozone exposure is also necessary for future cost benefit analysis particularly when comparing abatement costs.

5 Information to the public

Public are advised to reduce exposure to ground level ozone by taking the following precautions:

- Limiting strenuous outdoor activity between 1.00 pm and 3.00 pm when ground level ozone concentration is usually highest.
- Opting to pump petrol for their vehicles in early morning or late evening hours when the temperature is cooler that can reduce VOC fugitive emission.
- Reducing energy consumption that reduce the emission from power utilities.

Glossary

NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
O	Oxygen radical
O_2	Oxygen
O_3	Ozone
UV	Ultraviolet rays from the sun
EURO 5	European vehicle emission standards (stage 5)
VOC(s)	Volatile organic carbon(s)

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