

## Nox and Sox Emissions and Climate Changes

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**Abstract:** NO<sub>x</sub> and SO<sub>x</sub> evolved from diesel engines, fuel combustion, etc. led to much human health hazardous. This review aimed to discuss the relationship between the emitted gases and the future climatic changes from two scientific points of view. The scientists based their predictions according to different scientific evidences, which categorized into two main groups; the first predicts decline air pollution and climatic changes till 2050. While the second predicted increase in air pollution and climatic changes till 2030.

**Key words:** Nox • Sox • Greenhouse • Climatic Changes • Air Pollution

### INTRODUCTION

Sulfur dioxide (SO<sub>2</sub>) is a gas formed when sulfur is exposed to oxygen at high temperatures during fossil fuel combustion, oil refining, or metal smelting. SO<sub>2</sub> is toxic at high concentrations, but its principal air pollution effects are associated with the formation of acid rain and aerosols. SO<sub>2</sub> dissolves in cloud droplets and oxidizes to form sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), which can fall to Earth as acid rain, snow, or form sulfate aerosol particles in the atmosphere [1].

Nitrogen oxides (NO and NO<sub>2</sub>, referred together as No<sub>x</sub>) are highly reactive gases formed when oxygen and nitrogen react at high temperatures during

combustion or lightning strikes. Nitrogen present in fuel can also be emitted as NO<sub>x</sub> during combustion. Emissions are dominated by fossil fuel combustion at northern mid-latitudes and by biomass burning in the tropics. Figure (1) shows the distribution of No<sub>x</sub> emissions to the atmosphere in 2006 as determined by satellite measurements of atmospheric NO<sub>2</sub> concentrations. In the atmosphere, NO<sub>x</sub> reacts with volatile organic compounds (VOCs) and carbon monoxide to produce ground-level ozone through a complicated chain reaction mechanism. It is eventually oxidized to nitric acid (HNO<sub>3</sub>). Like sulfuric acid, nitric acid contributes to acid deposition and to aerosol formation [2].

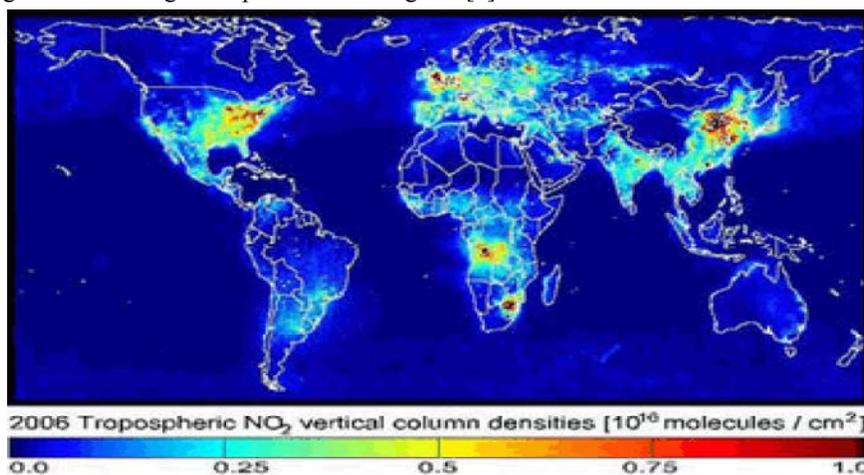


Fig. 1: Satellite observations of tropospheric NO<sub>2</sub>, 2006 (Source: Courtesy Jim Leason, USA and Pepijn Veefkind, KNMI, National Aeronautics and Space Administration).

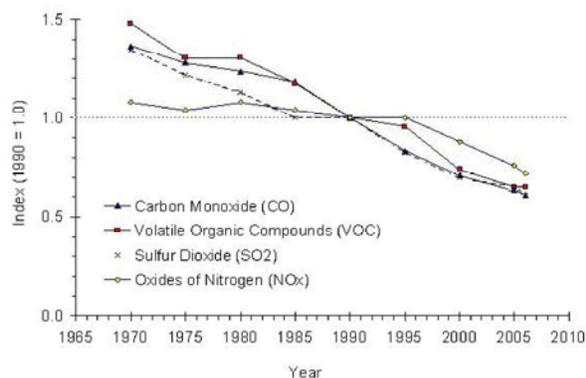


Fig. 2: Trends in Estimated U.S. Air Pollutant Emissions, 1970-2006 (Source: Environmental Protection Agency [4]).



Fig. 3: Catalytic converter mounted in a car's exhaust system. (Source: Courtesy Wikimedia Commons, Public Domain).

Today coal combustion is a major contributor to urban air pollution in China, especially from emissions of SO<sub>2</sub> and aerosols. Air pollution regulations in developed countries have reduced industrial smog events, but photochemical smog remains a persistent problem, largely driven by vehicle emissions. Photochemical smog forms when NO<sub>x</sub> and Volatile organic compounds (VOCs) react in the presence of solar radiation to form ozone. The solar radiation also promotes formation of secondary aerosol particles from oxidation of NO<sub>x</sub>, VOCs and SO<sub>2</sub> [3].

**Controlling Air Pollution:** Thanks to several decades of increasingly strict controls, emissions of most major air pollutants have declined in the U.S. and other

industrialized countries since the 1970s. Figure (2) shows the aggregate decrease in U.S. emissions since 1970. This trend occurred even as economic activity and fuel consumption increased. The reductions came about because governments passed laws limiting allowable pollution levels and required the use of technologies to reduce emissions, such as scrubbers on power plant smokestacks and catalytic converters on vehicles (Figure 3). This decrease in emissions has demonstrably reduced levels of the four principal primary pollutants: carbon monoxide, nitrogen dioxide, sulfur dioxide and lead. Air quality standards for these four pollutants were frequently exceeded in the U.S. twenty years ago but are hardly ever exceeded now [4, 5].

In contrast to improvements in developed countries, air pollution has been worsening in many industrializing nations. Beijing, Mexico City, Cairo, Jakarta and other megacities in developing countries have some of the dirtiest air in the world. This situation is caused by rapid population growth combined with rising energy demand, weak pollution control standards, dirty fuels and inefficient technologies. Some governments have started to address this problem, for example, China is tightening motor vehicle emission standards, but much stronger actions will be required to reduce the serious public health impacts of air pollution worldwide [6].

**Future Air Pollution Levels and Climatic Changes:**

Tagaris *et al.* [7] predict that between 2001 and 2050, mean summer 8-hour ozone levels over the U.S. will decline by 11% to 28%, depending on the region, with an average decline of 20%. Fine particulate matter (PM<sub>2.5</sub>) will decline by 9% to 32%, with an average decline of 23%. Their results stand in marked contrast to previous studies, nearly all of which predict higher air pollution levels over the U.S. in the future [8-10].

However, Tagaris *et al.* [7] modeling includes the effect of required declines in pollution emissions that have been occurring and will continue over the next few decades. On the other hand, previous studies have assumed constant or increasing emissions of air pollutants. In fact, as show below, even Tagaris *et al.* [7] predictions are too pessimistic. Air pollution will decline even more than they suggest.

Climate and regional pollution models predict that, assuming no changes in pollutant emissions, a warmer climate will tend to increase air pollution in some areas of the U.S.A major reason for this is a greater likelihood of multi-day “stagnation” events, creating more

opportunities for pollution to build up over several days. Warmer temperatures also increase natural emissions of volatile organic compounds (VOC). But climate change won't be all bad for air pollution. Higher temperatures also reduce particulate levels by preventing the condensation of "semi-volatile" compounds, like ammonium nitrate and some organics. More frequent summer rains in some areas would also tend to reduce ozone levels.

Overall, Tagaris *et al.* [7] project that climate change alone will have little net effect on national-average levels of ozone or PM<sub>2.5</sub>, though there would likely be regional variation, with some areas experiencing higher and some lower pollution levels. Even this is an advance over previous studies, which have tended to focus only on regions (i.e., the Northeast) and pollutants (i.e., ozone) where climate warming is most likely to increase future levels, while ignoring potential air pollution benefits from warming.

But Tagaris *et al.* [7] based their estimates of future pollution levels on a realistic projection of future emissions. They assume, for example, that North American emissions of oxides of nitrogen (NO<sub>x</sub>, the sum of NO and NO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>) will decline 50% between 2001 and 2050, while anthropogenic non-methane volatile organic compounds (NMVOC) will decline a little over 40%. On the other hand, natural NMVOC emissions increase more than 20% in their model, due to warmer temperatures, resulting in no net change in total NMVOC emissions over time.

Based on these assumptions, combined with the IPCC's A1B scenario for future of greenhouse gas emissions and consequent warming, Tagaris *et al.* [7] concluded that between 2001 and 2050 the number of days per year exceeding the federal 85 ppb, 8-hour ozone standard will decline between 60% and 100%, depending on the region/metropolitan area. Tagaris *et al.* [7] model projects large declines in particulate levels as well—a 34% to 80% reduction in the number of days per year exceeding EPA's new daily PM<sub>2.5</sub> standard of 35 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) (the entire nation already complies with the previous standard of 65  $\mu\text{g}/\text{m}^3$ ).

So why should we believe Tagaris *et al.* [7] prediction of declining pollution emissions and not previous studies' prediction of increasing emissions? First of all, declining emissions is what you would predict based on current trends. Figure (2) shows EPA's estimate of pollution emissions from 1970-2006. All values are scaled to a

common index of 1.0 in 1990, so that percentage changes over time can be compared on the same scale. The underlying emissions estimates for the chart are available from the EPA.

Second, based on existing regulatory requirements, we should expect declining pollution levels to continue for decades to come. EPA's Clean Air Interstate Rule (CAIR) requires power plant SO<sub>2</sub> and NO<sub>x</sub> emissions to decline more than 70% and 60%, respectively, during the next two decades, when compared with 2003 emissions. Recently implemented requirements for new automobiles and diesel trucks and upcoming standards for new off-road diesel equipment will eliminate more than 80% of their VOC, NO<sub>x</sub> and soot emissions during the next few decades, even after accounting for growth in total driving. Dozens of other federal and state requirements will eliminate most remaining emissions from other sources of air pollution.

Third, real-world measurements show that, if anything, Tagaris *et al.* [7] understate future improvements in pollution emissions and levels. You can see this by comparing current trends to Tagaris *et al.* [7] predictions. For example, Tagaris *et al.* [7] assume total NO<sub>x</sub> emissions will decline 14% between 2001 and 2020 [2]. In fact, NO<sub>x</sub> emissions already declined 18% between 2000 and 2006 [4]. Also, they assume VOC emissions will decline 22% between 2001 and 2020. But EPA estimates VOC emissions already declined by 12% between 2000 and 2006. Furthermore, most VOC emissions come from gasoline vehicles and on-road measurements show these are dropping at a rate of about 10% per year [11-13].

Ambient pollution trends also show faster declines than Tagaris *et al.* [7] assumptions suggest. According to Tagaris *et al.* [7], national-average PM<sub>2.5</sub> levels will drop about 23% between 2001 and 2050. But average PM<sub>2.5</sub> dropped 10% from just 2001 to 2006 [5]. Tagaris *et al.* [7] predict a 20% decline in summer-average ozone during the same period. But summer-average ozone levels for 2004-06 were already 6% lower than for 2000-2002. In addition, ozone-precursor pollutants—NO<sub>x</sub>, VOC and CO—are dropping faster than Tagaris *et al.* [7] assume. Thus, even though Tagaris *et al.* [7] are the first researchers who attempted a realistic appraisal for the future of air pollution levels; their estimates should be considered a worst-case upper limit on future emissions.

In contrast to Tagaris *et al.* [7], previous studies of climate change and air pollution are patently unrealistic. Sitch *et al.* [10] assumption of increasing air pollution emissions is the polar opposite of observed trends and

regulatory requirements. Mickley *et al.* [9] hold CO and black carbon emissions constant and then use the GISS general circulation model to predict that peak CO and BC levels in the Northeast would rise 5% to 10% in 2050 under the IPCC's A1B scenario. Although the introduction to their paper makes a passing mention of the importance of future pollutant emissions, the rest of the article leads readers to believe that future of air pollution levels will be higher than current levels. Mickley *et al.* [9] also gave reporters this impression in a press release on her research sub-titled "summertime pollution may intensify in the northeastern and Midwestern U.S. due to global warming" [14]. He was more forthcoming in a guest column on Real Climate, but still omitted the fact that future pollution emissions will be much lower than today and that this is far more important than climate change for future air pollution levels.

Knowlton *et al.* [8] used EPA's NOx and VOC emissions estimate for 1996 to predict ozone levels after 2050. In response, Knowlton *et al.*[8] claimed that their study wasn't actually intended to predict likely future ozone levels, but was merely a feasibility study (though they also expressed the mistaken view that NOx and VOC emissions would increase in the future). They performed their study on behalf of the Natural Resources Defense Council, an environmental activist group and several members of the Knowlton *et al.*[8] team also co-authored the NRDC report Heat Advisory [15, 16], leaving little doubt about the true purpose of the research. Although Knowlton *et al.*[8] appeared in a prestigious peer-reviewed scientific journal, the whole exercise was pre-determined to produce the ideologically desired answer-air pollution will increase in the future due to climate change-rather than the scientifically justifiable answer-air pollution will decline in the future, regardless of climate change [17].

### CONCLUSION

The proposition that air pollutant emissions will sharply decline in the future is far more certain than any predictions of how and why the Earth's climate will change due to greenhouse gas emissions (NOx, SOx, CO, VOC, etc...). Moreover, Policy-relevant information must be provided and the scientists should begin with a realistic estimate (or reasonable range of estimates) for future pollutant emissions and then apply these emissions to two climate scenarios: a baseline with no future warming and then a scenario (or scenarios) with warming.

Table 1: Comparison of stratospheric ozone depletion and global warming

	Ozone depletion	Global warming
Location	Stratosphere	Troposphere (stratosphere actually cools)
Causative pollutant	Ozone-depleting substances (NO <sub>x</sub> , CFCs)	Greenhouse gases (CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, tropospheric ozone)
Process	Catalytic ozone loss reactions	Trapping of infrared radiation emitted by Earth's surface

This would isolate the effect of future warming on future air pollution (Table 1).

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