

Cover Story

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# Out of Tackling Asia's Air Crisis Breath

Asia's extraordinary economic growth since the Second World War has come at an enormous price to the environment, and above all, on its air.

For this cover package, Associate Managing Editor John Delury and Editorial Board member Peter Hayes assembled an international team of experts to look at the challenges posed. In particular, we sought to look at both the science and the policy-making behind the problems.

A short package of essays on an issue of this complexity cannot hope to be comprehensive, but we do aim to highlight key issues and how they might be addressed. One major conclusion is that air pollution in Asia is a problem that cries out for regional cooperation, precisely because it is transboundary in nature, as numerous authors in this cover package point out.

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# Tackling Southeast Asia's Air Pollution

By Moekti H. Soejachmoen

**Air quality across Southeast Asia has been getting steadily worse for decades. The deterioration is a combination of local pollution and pollution from upwind regions influenced by the dynamics of the atmosphere in the area, which is around the equator.**

**Transboundary air pollution in the region urgently needs regional collaboration and science-based policy-making to tackle it, writes Moekti H. Soejachmoen.**

CHRONIC AND SEVERE haze events in Southeast Asia in recent decades have attracted the attention of governments and the public due to their impact on local economies, air quality and public health because the events have become more intense and frequent in recent years. Widespread biomass burning activities, including forests and peatland burning, are one of the major sources of haze and they play an important role in degrading air quality in Southeast Asia. Aerosols emitted from such fires can cause persistent haze events under certain weather conditions in downwind locations, degrading visibility and causing human health issues.

This article is based on a number of studies that have been conducted in response to fire events in previous years, but not the one in 2019. Such studies tried to address a number of issues including atmospheric chemistry and physics, the impact on human health, degraded visibility, legal and institutional frameworks to address the issue, as well as the impact on the economy.

According to studies conducted by Hsiang-He Lee and her team, burning biomass contributed to up to 40-60 percent of haze events in the major cities of Southeast Asia between 2003 and 2014. Because of the burning, the region, consisting of mainland Southeast Asia and the Maritime Continent, also suffered from a rise in carbonaceous compounds, including black carbon. As a result, sunlight can be reduced through both absorption and scattering in the atmosphere, causing low visibility. Such events have hindered daily activities, including economic activities, air transportation and even students on their way to school.

Besides haze events, biomass burning also resulted in significant increases in carbon dioxide (CO<sub>2</sub>) emissions, which led to increased temperatures and worsened climate change. During the period from Aug. 1 to Sept. 18, 2019, fires in Sumatra and Kalimantan emitted approximately 360 megatons of CO<sub>2</sub> (Mt CO<sub>2</sub>) compared to 400 Mt CO<sub>2</sub> over the same period in 2015.

## TRANSBOUNDARY AND LOCAL POLLUTION BOTH CONTRIBUTE

Cities in Southeast Asia suffer from both transboundary air pollution and their own local pollution, which results in urban haze. Lee and her team's study shows that out of the 35 most heavily polluted haze-event days in Singapore in October 2006, only 17 days were associated with major outbreaks of burning in adjacent parts of Indonesia, while local pollution levels enhanced by stable meteorological conditions were the main reasons for poor air quality on the other 18 days. Their trajectory analysis also indicated that pollution from Kalimantan in Indonesia had not reached Singapore during that haze period.

Another study also emphasized the contribution of local pollution to air quality in major cities in Southeast Asia. Their results showed that biomass burning in the region only contributed 39 percent, 36 percent and 34 percent of the low-visibility (<10km) days in, respectively, Bangkok, Kuala Lumpur and Singapore from 2003 to 2014. In attributing the low-visibility events to fire emissions from different sites, the study found that mainland Southeast Asia is the major contributor during the northeast or winter monsoon season in the region, while in the southwest or summer monsoon season, most fire aerosols come from Sumatra and Borneo.

On the other hand, another study shows that the intense haze episode of June 2013, a long-lasting event with a "very unhealthy" air pollu-

tion level in Singapore, was caused by enhanced fire aerosol transport from Sumatra to West Malaysia, owing to a tropical cyclone located in the South China Sea. Such climate variability and meteorological phenomena affect not only biomass burning emissions but also the transport of fire aerosols. The seasonal migration of the intertropical convergence zone (ITCZ) and the associated monsoon dominate seasonal wind flows, whereas sea breezes, tropical cyclones and topography determine air flow on smaller spatial and temporal scales. All of these phenomena play significant roles in determining the transport pathway of fire aerosols.

Aerosols emitted from fossil fuel burning alongside other non-biomass burning activities also contribute significantly to air quality degradation. Such particulate pollutants include local pollutants and those pollutants brought in from neighboring regions by long-range transport. Advancing our understanding of the respective contributions of aerosols from fire (i.e. biomass burning) versus non-fire (including fossil fuel combustion, road and industrial dust, land use and land changes, etc.) activities on air quality and visibility degradation has become an urgent task for developing effective air pollution mitigation policies in Southeast Asia. This is even more important as fossil fuel emissions in the region have increased significantly in recent years, while energy demands are growing rapidly in response to economic expansion and demographic trends.

## THE ROLE OF ATMOSPHERIC DYNAMICS

Aerosols from fires affect climate indirectly, and this is even more complicated due to various cloud types and meteorological conditions in the Maritime Continent. Based on a study, there is a relationship between the appearance of fire hotspots and weather phenomena and climate variabilities over the Maritime Continent, includ-

ing: 1) the El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD); 2) seasonal migration of the Inter-tropical Convergence Zone (ITCZ) and associated Southeast Asian monsoons; 3) intra-seasonal variability associated with the Madden–Julian Oscillation (MJO) and the west Sumatran low; 4) equatorial waves, mesoscale features, and tropical cyclones; and 5) convection. The influence of these factors on fire events varies over different parts of the Maritime Continent. The fire signal in one part of Kalimantan is strongly related to both the monsoons and ENSO; while the one in Central Sumatra is closely tied to the MJO.

Lee's study suggests further research is needed to improve the current estimate of the spatiotemporal distribution of fire emissions, in addition to total emitted quantities from the fire hotspots. This is based on the discrepancy in modeled low visibility events arising from the use of different meteorological datasets, especially in the results from Bangkok and Kuching. Such discrepancies were also shown in the use of different emission inventories, which resulted in substantial differences in modeled fire aerosol concentration and visibility, especially in Bangkok and Singapore.

The study also defined and derived a metric of “haze exposure days” (HEDs), by integrating the annual low-visibility days of 50 cities in ASEAN weighted by population or averaged arithmetically. The result shows that a very large number of people in Southeast Asia have been exposed to relatively persistent hazy conditions, with the top four cities in the HED ranking being Jakarta, Bangkok, Hanoi and Yangon. With a total population exceeding 30 million, all have experienced more than 200 days per year of low visibility due to particulate pollution over the past decade and more than 50 percent of those low-visibility days were mainly due to fire aerosols. Such events have been increasing steadily not only in high-



A burning forest in Central Kalimantan, Indonesia in September, one of a number of fires in Sumatra and Borneo that caused thick haze in the neighboring countries, Singapore and Malaysia.

Photo: EPA/Fully Handoko

population cities but also those with relatively low populations.

Forest and peatland fires in Indonesia have played the biggest role. The fire itself happened as a result of several incidents, namely more intense long and hot dry seasons due to climate change. This is worse as most fires happen in peat areas, especially in Sumatra and Kalimantan, which made it spread from forests to the earth itself, making it harder to extinguish flames when the land and weather are dry. Large fires during the last decades were exacerbated by drought brought on by the El Niño Southern Oscillation (ENSO). The delay of the monsoon in ENSO years means that fires burn for several months longer than usual.

#### TRANSNATIONAL COLLABORATION IN THE REGION IS A MUST

It is clear that air pollution is not only a local issue. Because air has no border, air pollution problems can only be solved either by regional co-operation or global environmental laws, which do not yet exist. There is an urgent need for innovative transboundary international environment law to check those nations that are the source of the pollutants from further deterioration. Concerned neighbors may resolve transboundary air pollution issues co-operatively and harmoniously.

Transboundary atmospheric/air pollution problems exist between countries. Some examples are those between China, Japan and Hong Kong; between Canada, the US, and Mexico;

between Africa, Europe and Finland; between Indonesia, Singapore and Malaysia; between India and Pakistan; and between South Africa and Botswana. A number of agreements have been signed, including the Convention on Long-Term Transboundary Air Pollution in Europe; the ASEAN Agreement on Transboundary Haze Pollution (AATHP); the EANET program in East Asia and the long-range transboundary air pollution program in Northeast Asia.

AATHP faces numerous issues that hinder effective enforcement. One is limited understanding of the link between pollution emissions and their presence and effects in receiving locations (the so-called source-receptor relationship). In a dynamic region covering a huge geographical area such as

Southeast Asia, such issues pose a major obstacle to resolving the multitude of challenges relating to transboundary air pollution.

#### THE NECESSITY OF SCIENCE-BASED AND INFORMED POLICY-MAKING

In their review, Qinqin Chen and David Taylor mention that to better understand the source-receptor relationship in the region, there are a number of challenges, including: 1) insufficient in-situ sampling and measurement of atmospheric pollutants; 2) uncertainties in space-borne observation; and 3) incomplete emission inventory analysis (EIA) in the region.

The current trajectory models cannot differentiate between pollution sources located different distances away; to reduce this uncertainty, one possible solution is to conduct EIA in receptor areas and check the local meteorological conditions to have a better understanding of local emissions and local weather conditions during the period of interest before interpreting the trajectory results.

The objects of trajectory models are air parcels, not pollutants. During transportation, pollutants undergo dry/wet deposition, resuspension, and physicochemical changes; these changes affect the travel distances of pollutants, and this process cannot be simulated in the model. For better simulation results, researchers could couple dispersion functions with their trajectory calculations, by either choosing Chemical Transport Models (CTMs) instead of trajectory models or combining the trajectory results with the dispersion calculation results from CTMs. Chosen trajectory modeling times are normally less than five days, while the starting height of air parcels above the potential source is actually not near ground surface; proving that pollutants in air parcels 0.5 km above the assumed pollution source are actually

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from the source is difficult. Chances are that the potential pollution source is also a receptor, since many pollutants are able to suspend in the air for more than five days. Therefore, caution is advised when interpreting trajectory results, and other source apportionment approaches should also be considered for validation. Simply using forward trajectory calculations, starting from the potential sources, may also be beneficial.

It is important to understand pollutant behavior during transportation using CTMs as pollutants. In tropical areas with relatively high levels of UV radiation and temperature, these can undergo chemical transformation during transportation. CTMs can simulate changes of pollutant concentrations during the entire transportation process. Simulations of secondary pollutants and microphysical changes of aerosols are more problematic, especially in the case of Southeast Asia, where relatively dense stands of forest can still be found in a region that is predominantly marine. The formation of Secondary Organic Aerosol (SOA) is harder to simulate accurately in CTMs owing to the presence of both biogenic and anthropogenic SOA precursors (sea salt, reactive nitrogen, CO, hydrocarbon, etc.). Problems in accurately simulating conditions also arise because of a shortage of accurate emission inventory input data and knowledge of chemical transformations of pollutants in the environment. The results of the model are also influenced by estimated injection heights of smoke plumes, which directly affects the simulation of pollutant mixing, chemical reactions and transport distances. It is also hard to estimate correctly the smoke injection height in Southeast Asia due to different types of biomass burning and ambient meteorological conditions. One possible solution to these problems is to conduct in-situ sampling and measurement campaigns.

Another important element is understanding

the contribution of transboundary air pollution because the results from different geographical sources provide valuable information for policy-making. It is important because contribution apportionment requires the understanding of both local pollution and transboundary air pollution, the possibility of overlooking or underestimating local pollution (or TAP) is reduced.

There is the possibility of different interpretations under the same TAP context from different points of view, namely: local pollution is decreasing, which implies TAP is the only reason for poor local air quality, or local pollution is still serious, which implies both local pollution and TAP are responsible. Due to their added complexity, the number of contribution studies is far fewer than the number of simple source appointment, back-trajectory studies. Future studies ought to consider local emission analysis and results of an examination of the contribution of TAP, thereby providing decision-makers with a basis for comprehensive, balanced and holistic understanding.

Another big challenge for Southeast Asia is the absence of data from several countries in the region, while a large proportion of the sediment records that are available are poorly resolved and insufficiently well dated, or not dated at all.

In the shorter term, Southeast Asian countries need to consider improved collection and monitoring of pollution data, including by deploying more ground-based air quality observation stations, conducting regional field campaigns that allow TAP to be distinguished in Southeast Asia, and making country-level EIAs routine. Understanding local pollution is important in transboundary air pollution issues. Information on local pollution has the potential to provide an unbiased understanding of pollution levels in receptor areas.

Such actions cannot be done without regional co-operation and the political will to implement

