Projecting the air quality and health impacts of proposed coal-fired power plants in Japan

Lauri Myllyvirta, coal and air pollution specialist, Greenpeace
Clifford Chuwah, PhD, Greenpeace Research Laboratories, Exeter University, UK

Emissions projections

Total air pollutant emissions from a coal-fired power plant can be calculated by multiplying the flue gas concentration of each pollutant by the total volume of flue gas discharged.

Data on the concentrations of pollutants in flue gas discharged by the power plants was compiled by Kiko Network from the Environmental Impact Assessments of the projects, taking into account all pollution control techniques that the project is planning to use. When data was not available from EIA documents, the median value for other projects of the same size was used. The flue gas concentration is expressed per cubic meter of dry flue gas in standard conditions.

Total flue gas volume was calculated based on CO2 emissions projections provided by Kiko Network. Volume of dry flue gas in standard conditions is closely related to CO2 emissions. Total volume of flue gas per tonne of CO2 emissions was calculated from EEA (2008, Tables D.1 and D.2).

Locations of the proposed power plants and their stack characteristics (stack height and diameter; flue gas release velocity and temperature) were similarly compiled from the EEA documents and median values from compiled data were used when project-specific data was not available.

To 30% of emitted fly ash was assumed to be PM2.5, and 37.5% PM10, in line with the U.S. EPA AP-42 default value for electrostatic precipitators. Particles larger than 10 microns were modeled with a mean aerodynamic diameter of 15 microns. Reported annual emissions were converted into average emission rates, which were then applied throughout the year.

Atmospheric modeling

Atmospheric dispersion modeling for the case studies was carried out using version 7 (June 2015) of the CALPUFF modeling system. CALPUFF is an advanced non-steady-state meteorological and air quality modeling system adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts.

A full calendar year of data was used for the simulations to capture seasonal variation. Year 2014 was chosen based on representativeness of observed weather statistics (wind speed, wind direction, temperature, humidity and precipitation).

Meteorological data for the simulations comes from two sources: 38 hourly surface meteorological observation stations for which data was available through U.S. NCDC under the World Meteorological

Organization agreement on sharing meteorological data, and three-dimensional meteorology generated in the TAPM modeling system, developed by Australia's national science agency CSIRO. TAPM uses as its inputs global weather data from the GASP model of the Australian Bureau of Meteorology, combined with higher-resolution terrain data. The TAPM outputs were validated against surface observations.

TAPM outputs were converted into formats accepted by CALPUFF's meteorological preprocessor, CALMET, using the CALTAPM utility, and the meteorological data were then prepared for CALPUFF execution using CALMET. CALMET generates a set of time-varying micrometeorological parameters (hourly 3-dimensional temperature fields, and hourly gridded stability class, surface friction velocity, mixing height, Monin-Obukhov length, convective velocity scale, air density, short-wave solar radiation, surface relative humidity and temperature, precipitation code, and precipitation rate) for input to CALPUFF.

Terrain height and land-use data were also prepared using the TAPM system and global datasets made available by CSIRO. A two nested grids with a 75x75 grid size, horizontal resolutions of 20km and 10km and 12 vertical levels were used to cover the modeled power plants in as much detail as possible.

A separate simulation was set up for each power plant, except that power plants less than 5km apart from each other were grouped into clusters. For the pollution dispersion simulations, concentric receptor grids with 1.25km, 2.5km, 5km and 10km, along with the 20km grid covering the entire domain, were used to obtain higher-resolution results in the area surrounding the modeled source.

Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA/RIVAD chemistry module within CALPUFF, requiring data on ozone, ammonia and H2O2 concentrations to drive atmospheric chemistry. Hourly ozone levels for 58 locations across the modeling domain were obtained from government monitoring data. As measured data for ammonia and H2O2 was not available, monthly average levels for the modeling domain were imported into the model from baseline simulations using the Geos-Chem global atmospheric model with nested grid for Southeast Asia (Koplitz et al 2017).

The CALPUFF results were reprocessed using the POSTUTIL utility to repartition different nitrogen species (NO, NO2, NO3 and HNO3) based on background ammonia concentrations. Gridded annual average pollutant concentrations and daily average concentrations were output using CALPUFF for further analysis.

Health impacts

The health impacts resulting from the increase in PM2.5 and ozone concentrations were evaluated following the health impact assessment methodology of the Harvard-Greenpeace coal-health study (Koplitz et al., 2017). The study used risk ratios for PM2.5 exposure derived by Krewski et al (2009, Table 11), applied in line with recommendations given by the authors to U.S. EPA (2010). In addition, premature deaths from NO2 exposure and respiratory symptoms in children due to PM10 and NO2 exposure were assessed based on WHO (2013) recommendations, and increase in low birth weight births was assessed based on Dadwand et al (2013).

As the CALPUFF modeling system is not suited for projecting ozone enhancements, increases in ozone levels were based on the Koplitz et al. (2017) results.

The fundamental equation used for projecting increases in health impacts, based on Anenberg et al (2010) is:

$$\Delta y_{ij} = y_{0ij}\left(1 - exp^{-\beta_i \Delta x_j}\right) p_j$$

where Δy is the change in mortality, y_0 is the baseline mortality, p is the population in the applicable age group, Δx is the change in concentration, i is the specific cause of mortality and j is the country. β is the coefficient in the regression equation of the effect estimate for the specific mortality cause:

$$RR = exp^{\beta \Delta X}$$

where RR is the risk ratio reported in the original study and ΔX is the concentration change for which the risk ratio is reported.

Baseline death rates y_0 in Japan from different causes were obtained from WHO Global Health Estimates (2014), birth rates and incidence of low birth weight from World Bank (undated). Baseline rates of asthma incidence and bronchitic symptoms among asthma sufferers in Japan were sourced from Asthma prevalence from Akasawa (2015) and Global Asthma Report 2014 (GAN 2014), respectively. Averages for the 6-7 and 13-14 age groups were used as the average for the entire appropriate age group.

Risk ratio for 10µg/m³ increase in annual average PM exposure	**Pollutant**	**Age group**	**Central**	**95% CI, low**	**95% CI, high**	**Reference**
Cardiopulmonary diseases	PM2.5	≥30	1.128	1.077	1.182	Krewski et al 2009
Ischemic heart disease	PM2.5	≥30	1.287	1.177	1.407	Krewski et al 2009
Lung cancer	PM2.5	≥30	1.142	1.057	1.234	Krewski et al 2009
Low birth weight	PM2.5	N/A	1.100	1.030	1.180	Dadwand et al 2013
Asthma symptoms in children	PM10	5-19	1.021	0.99	1.06	HRAPIE 2013

Risk ratio for 10µg/m³ increase in annual average NO2 exposure	**Age group**	**Central**	**95% CI, low**	**95% CI, high**	**Reference**
Deaths, all causes	≥30	1.062	1.04	1.083	WHO 2013

Bronchitic symptoms in children	5-14	1.028	1.006	1.051	HRAPIE 2013

Table 1 Risk ratios from different studies used for health impact assessment.

References

Akasawa A et al, 2015. Time Trends in the Prevalence of Asthma in Japanese Children. Journal of Allergy and Clinical Immunology 135(2), AB229. https://doi.org/10.1016/j.jaci.2014.12.1681

Anenberg SC et al, 2010. An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. Environ. Health Perspect. 2010, 118 (9), 1189. https://ehp.niehs.nih.gov/0901220/

Dadvand P et al, 2013. Maternal Exposure to Particulate Air Pollution and Term Birth Weight: A Multi-Country Evaluation of Effect and Heterogeneity. Environmental Health Perspectives. http://ehp.niehs.nih.gov/pdf-files/2013/Feb/ehp.1205575.pdf

Global Asthma Network (GAN), 2014. Global Asthma Report 2014. Auckland, New Zealand. http://www.globalasthmareport.org/resources/Global_Asthma_Report_2014.pdf

European Environment Agency (EEA), 2008. Air pollution from electricity-generating large combustion plants. Technical report No 4/2008.

Koplitz et al 2017: Burden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia. Environmental Science & Technology. http://dx.doi.org/10.1021/acs.est.6b03731

U.S. EPA , 2010: Quantitative Health Risk Assessment for Particulate Matter; United States Environmental Protection Agency, Office of Air Quality Planning and Standards: Research Triangle Park, NC. https://www3.epa.gov/ttn/naaqs/standards/pm/data/PM_RA_FINAL_June_2010.pdf

World Bank (WB), World Development Indicators. http://databank.worldbank.org/data/home.aspx

World Health Organization (WHO), 2013. Health risks of air pollution in Europe-HRAPIE project. http://www.euro.who.int/__data/assets/pdf_file/0017/234026/e96933.pdf?ua=1

World Health Organization (WHO), 2014. Global Health Estimates. http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html