Projecting the health impacts of alternative phase-out timelines for the Šoštanj power plant

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Abstract

The Šoštanj lignite power plant is ranked the most polluting industrial facility in Slovenia by the European Environment Agency (2014). The retirement timetable of the plant is currently being debated, affecting the lifetime of both the plant and the Velenje lignite mine that supplies the plant.

Air pollutant emissions from the plant expose a large number of people to $PM_{2.5}$, NO_2 and mercury pollution, increasing the risk of diseases such as stroke, lung cancer, heart and respiratory diseases in adults, as well as respiratory infections and harm to cognitive development in children. If the plant operates until 2042, we project approximately 1,100 deaths due to exposure to air pollutants and mercury from the plant (95% confidence interval: 680–2,100) from 2020 onwards. The total economic costs associated with the health impacts would be EUR2.7 billion (1.7–3.9). If the plant is retired in 2033, the number of deaths could be reduced to 780 (490–1,500) and economic damages to EUR2.0 billion (1.2–2.9), avoiding approximately 290 deaths and costs of EUR700 million.

Results

This case study provides an analysis of the air quality, toxic and health impacts of the coal power plant and lignite mine in Šoštanj/Velenje, combining official emission data with detailed atmospheric modeling and existing epidemiological data and literature.

The air quality impacts of emissions from the power plant and mine were modeled using the CALPUFF dispersion model, which uses detailed hourly data on wind and other atmospheric conditions to track the transport, chemical transformation and deposition of pollutants, and is widely used to assess the short and long range impacts of emissions from industrial point sources and area sources. The model predicts the increases in hourly, daily and annual pollutant concentrations caused by emissions from the studied source.

Emissions from the power plant contribute to ambient concentrations of $PM_{2.5}$, NO_2 and SO_2, while the dust emissions from the mine increase ambient levels of $PM_{2.5}$ and PM_{10}, causing increases in the risk of both acute and chronic diseases and symptoms.

The effects of these increases in pollutant concentrations on public health were quantified following the recommendations of WHO for health impact assessment of air pollution in Europe.

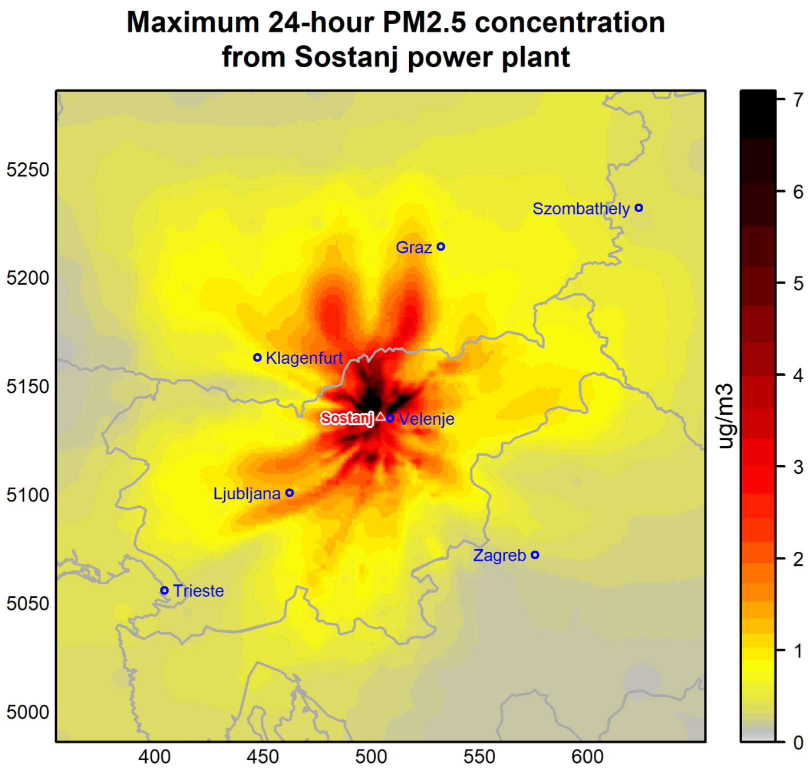

Figure 1. Modeled maximum 24-hour $PM_{2.5}$ concentrations attributed to the Šoštanj power plant at average emissions rates.

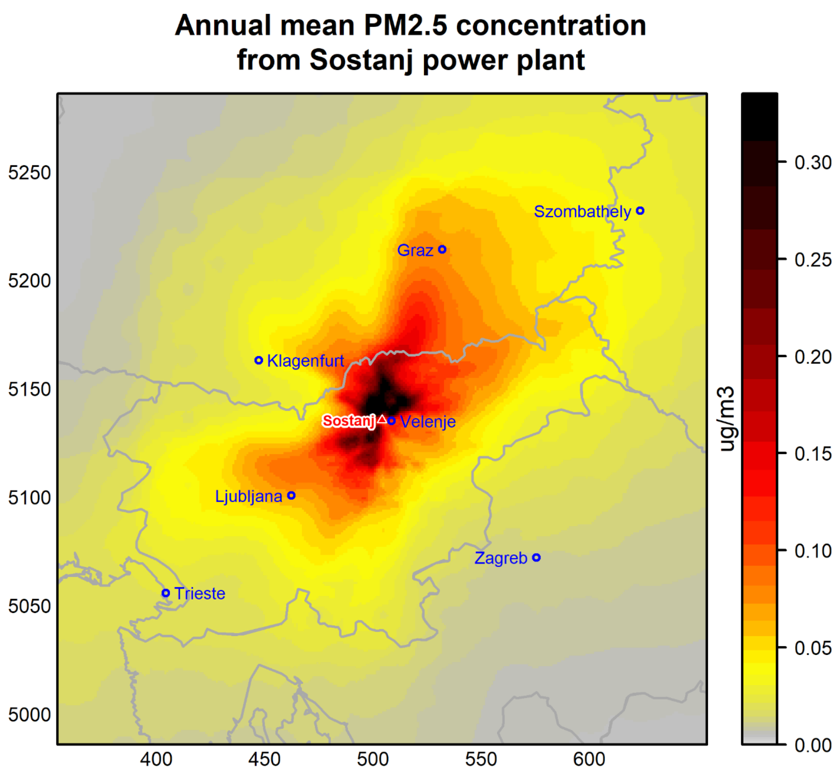

Figure 2. Modeled annual average $PM_{2.5}$ concentrations attributed to the Šoštanj power plant at average emissions rates.

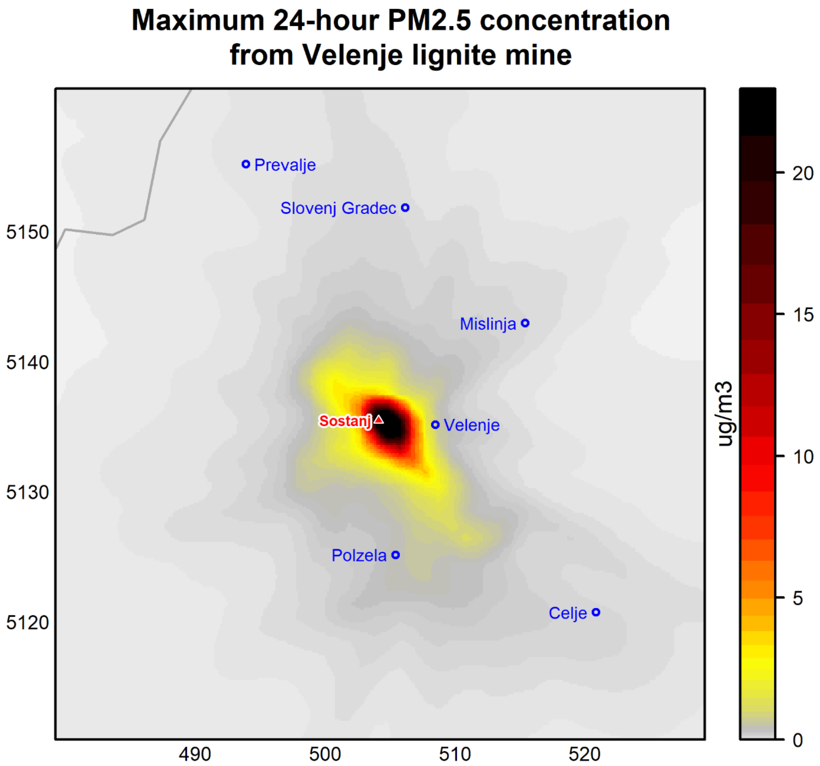

Figure 3. Modeled maximum 24-hour $PM_{2.5}$ concentrations attributed to the Velenje lignite mine.

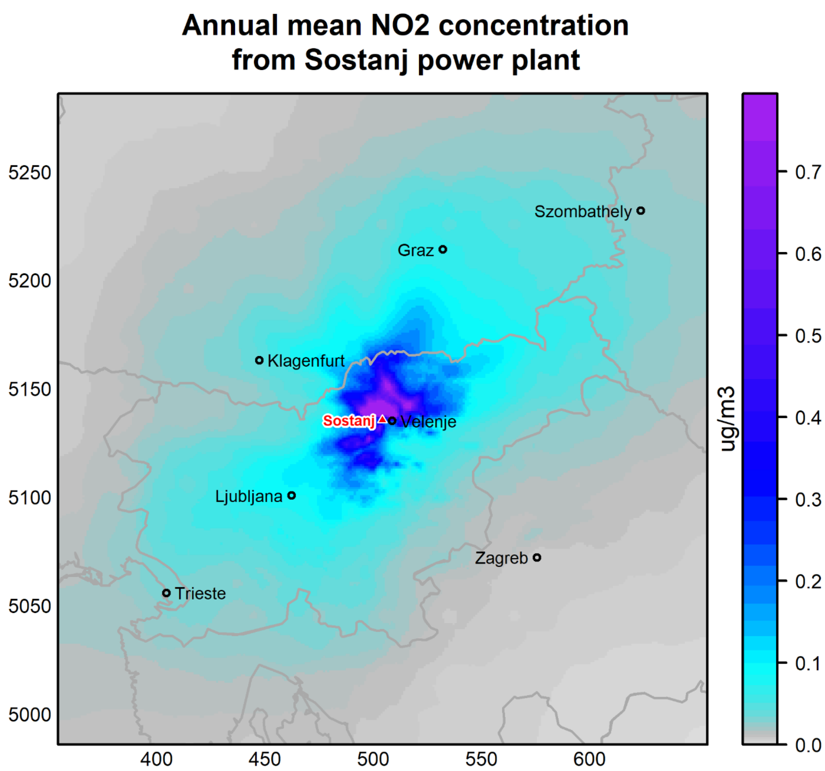

Figure 4. Modeled annual average NO_2 concentrations attributed to the Šoštanj power plant at average emissions rates.

Table 1. Projected health impacts and economic damage costs attributed to air pollutant emissions from the Šoštanj power plant and Velenje lignite mine, following different retirement timetables. “Low” and “high” values refer to 95% confidence intervals.

	Retired in 2033	Retired in 2038	Retired in 2042	Avoided with 2033 retirement, compared with 2042
deaths from air pollution	568	693	768	200
low	*359*	*438*	*485*	*126*
high	*837*	*1022*	*1132*	*295*
deaths attributed to mercury	215	272	308	93
low	*133*	*168*	*190*	*57*
high	*677*	*855*	*969*	*292*
total deaths due to pollution	783	964	1075	292
low	*492*	*606*	*675*	*183*
high	*1515*	*1877*	*2101*	*587*
external costs, mln EUR	2022	2469	2737	716
low	*1245*	*1519*	*1683*	*438*
high	*2903*	*3543*	*3927*	*1023*

Materials and methods

Projected future emissions from the plant, as well as coal consumption, were obtained from the Environmental report for the Slovenian national strategy for coal exit (Harmel M et al 2021, see Table 2). Annual air quality and health impacts were modeled using the annual average emissions rates in Table 3 and then scaled to match the cumulative totals. The power plant releases flue gases through the cooling tower; the resulting thermal plume rise was modeled in CALPUFF using the parameters in Table 4.

Dust emissions from the mine and the lignite transport to the power plant were calculated based on total lignite consumption and EMEP default emission factors (EMEP/EEA 2016). The locations of the mine working face and transport route were identified from Google Earth satellite imagery; the working face was modeled as an area source. The dust emissions in the model were doubled in dry summer conditions (24-hour mean relative humidity <65% and temperature >10°C).

Mercury emissions from the power plant were calculated from lignite consumption in Table 2, and Velenje lignite mercury content and release fraction in Kotnik et al (2000).

Table 2. Estimated coal consumption and air pollutant emissions from 2020 until retirement, in different retirement scenarios.

Retirement year	Estimated use of coal, cumulative (kt)	Estimated emissions from 2020 to until each considered year, cumulative (t)				
		SO_2	NOx	dust	mercury	$PM_{2.5}$ (mine)
2033	46,190	25,540	36,383	4,231	3.971	231
2038	58,327	30,255	43,456	5,174	5.015	292
2042	66,070	32,757	47,208	5,675	5.680	330

Table 3. Annual air pollutant emissions used for atmospheric modeling.

Source	Pollutant	Emissions	Unit
power plant	SO_2	1424	t/a
power plant	NO_x	2053	t/a
power plant	dust	247	t/a
power plant	mercury	247	kg/a
mine	$PM_{2.5}$	14	t/a

Table 4. Cooling tower discharge characteristics used for atmospheric modeling.

Stack height, m	Stack diameter, m	Flue gas velocity, m/s	Flue gas temperature, °C
164	50	3.8	50

Atmospheric dispersion modeling was carried out using version 7 (June 2015) of the CALPUFF modeling system. Meteorological and geophysical data for the simulations was generated with the TAPM model, developed by Australia's national science agency CSIRO. A set of nested grids with a 50x50 grid size and 30km, 7.5km and 2.5km horizontal resolutions and 12 vertical levels was used, centered on the power plant.

The CALPUFF model performs a detailed simulation of the rise of the plume from the power plant stack, through which the emissions are discharged; the characteristics of the modeled stacks are given in Table 2.

For emissions from main boilers of the power plants, 30% of emitted fly ash was assumed to be $PM_{2.5}$, and 37.5% PM_{10}, in line with the U.S. EPA AP-42 default value for electrostatic precipitators. Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA chemistry module within CALPUFF, and required data on ambient ozone levels was processed from measurements reported by the Slovenian government to the European Environmental Agency. Other required atmospheric chemistry parameters (monthly average ammonia and H_2O_2 levels) for the modeling domain were imported into the model from baseline simulations using the MSC-W atmospheric model (Huscher et al 2017). The CALPUFF results were reprocessed using the POSTUTIL utility to repartition different nitrogen species (NO, NO_2, NO_3 and HNO_3) based on background ammonia concentrations.

The health impacts resulting from the increase in $PM_{2.5}$ concentrations were evaluated by assessing the resulting population exposure, based on high-resolution gridded population data for 2015 from CIESIN (2018), and then applying the health impact assessment recommendations of WHO HRAPIE (2013), and economic valuation of health impacts in EEA (2014) as implemented in Huescher et al (2017). Baseline mortality for different causes and age groups was obtained from Global Burden of Disease results (IHME 2020). Economic valuations were adjusted to 2019 prices and income levels using data on GDP per capita in current prices from World Bank Databank (2020).

The health impacts of mercury emissions were calculated following the health impacts per kilogram of emissions for European coal-fired power plants derived by Nedellec&Rabl (2016).

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