ASSESSING THE AIR QUALITY, TOXIC AND HEALTH IMPACTS OF MARITSA EAST 2 POWER PLANT EMISSION DEROGATIONS

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SUMMARY

The Maritsa East complex is the largest concentration of operating coal-fired power plants and air pollutant emission sources in Bulgaria. Under new European emissions rules (LCP BREF), these plants would be required to substantially improve their air pollutant emission control, with potentially significant benefits for air quality and public health. However, the Maritsa East 2 plant operator has applied for wide-ranging, indefinite derogations that would allow far higher emission levels than those stipulated by EU regulation, with potentially significant impacts on the surrounding communities and ecosystems.

This case study provides a detailed analysis of the air quality, toxic and health impacts of the power plant, combining detailed atmospheric modeling with existing epidemiological data and literature. Dispersion and chemical transformation of pollutants is modeled using specific hourly data on wind speeds and directions and other relevant meteorological conditions for Bulgaria and surrounding areas.

The study analyses two future scenarios: one in which derogations are granted, and another in which the minimum requirements of European emission limits (BREF limits) are enforced, albeit applying the weakened SO2 limit for domestic lignite. In both scenarios, the plant is assumed to emit as much as allowed under these limits.

The derogations would have substantial impacts on air quality and public health both in Bulgaria and far beyond the country's borders. The higher SO2 emissions allowed by the derogations would elevate the levels of toxic PM2.5 particles, as SO2 forms sulfate particles in the atmosphere. Exposure to these particles increases the risk of diseases such as stroke, lung cancer, heart and respiratory diseases in adults, as well as respiratory infections in children. This leads to premature deaths from these causes.

The emissions from the coal-fired power plant allowed under the derogation are likely to result in an estimated 420 premature deaths and 90 low birth weight births per year due to exposure to PM2.5 and NO2. Other impacts include 190 new cases per year of chronic bronchitis in adults, 1000 cases of bronchitis in children, 20 children per day suffering from asthma and bronchitic symptoms, and 1300 people per day suffering from illnesses such as respiratory infections, including 170 lost working days, due to exposure to air pollution from the power plant. Every year, 300 people are estimated to be hospitalized due to respiratory and cardiovascular illnesses attributed to air pollution from the plant.

If the derogated emission limits are applied over a 10-year period, the plant would be responsible for an estimated 4,200 premature deaths over this period. Approximately 1,500 of these premature deaths would be avoided if the plant complied with the BREF limits, even with the application of the weakened SO2 limit.

One quarter of the projected health impacts takes place in Bulgaria, with three quarters taking place in neighboring countries, with approximately 1,000 premature deaths in Bulgaria, 1,000 in Turkey, 600 in

Romania and 500 in Greece over a 10-year period. Over 10 years, approximately 1,100 premature deaths would be avoided outside Bulgaria in the BREF limits scenario.

The highest predicted daily average SO_2 concentrations attributed to the plant in the derogation scenario exceed the EU air quality standard of 125µg/m^3 over an area of 70km^2 and a population of approximately 3,000 people. However, this area lacks air quality monitoring stations.

At the closest air quality monitoring station in Galabovo, emissions from the plant contribute significantly to exceedances of 24-hour air quality standard for SO_2, with the largest predicted contribution from the plant to 24-hour average SO_2 level over the modeling period amounting to 26% of the standard. This location suffers from frequent SO_2 pollution episodes.

Furthermore, the emissions from the studied power plant expose an estimated 1.3 million people to SO_2 concentrations and 15,000 people to $PM_{2.5}$ concentrations exceeding WHO 24-hour guidelines, before considering any other emission sources in the region. This exposure carries a significant risk of acute respiratory symptoms, especially for vulnerable groups such as children, elderly people and people with pre-existing respiratory ailments.

Mercury deposition from the plant under the derogation scenario is projected to exceed levels which can cause health risks, over an area with 1.0 million inhabitants. In total, approximately 1,000kg of mercury per year is projected to be deposited on land as a result of emissions from the power plant.

All of the above impacts would be limited to a significant extent if the power plant was required to meet the emission limits in the LCP BREF: exceedances of WHO $PM_{2.5}$ guidelines would be eliminated and population exposed to exceedances of SO_2 guidelines would fall from 1.3 million to an estimated 33,000. Mercury emissions would be reduced by 3/4 and population exposed to potentially unhealthy rates of mercury deposition would fall from 1.0 million to 39,000.

AIR POLLUTANT EMISSIONS

Two different emission scenarios are modeled: the first scenario assumes compliance with the upper (more lenient) end of the BREF limit range[1] (BREF limits scenario) for NOx, particulate matter and mercury, as well as the weakened emissions limit for SO2 at plants burning domestic lignite; the second scenario assumes emissions under the derogated emissions limits granted to the operator (derogation scenario).. The SO2 limit in the first scenario, 320mg/Nm3, is based on a provision in the BREF document that sets a weaker upper limit for a lignite plant that “can demonstrate that it cannot achieve” the normal limits for lignite-fired plants “for techno-economic reasons”.

Data on air emissions and stack parameters is taken from the air quality modeling study prepared by the plant operator as a part of the derogation procedure.

Table 1. Basic parameters of the modeled sources.

Stack	Plant Units	Lon	Lat	Stack heigth, m	Diameter, m	Exit temperature, C	Flue flow, Nm3/s	Exit velocity, m/s
K1	1-4	26.1357	42.2535	135	8.2	66	950	22.5
K2	5-8	26.1355	42.2536	135	8.2	66	950	22.5
K5,6	9-10	26.1335	42.2541	135	9.1	71	1100	21.1
K7	11	26.1312	42.2553	135	6.5	70	650	24.5
K8	12	26.1309	42.2549	135	6.5	70	650	24.5

[1] Upper BATAELs (Best Available Technology Associated Emission Levels) given in the 2017 Best Available Technology Reference Document (LCP BREF). http://eippcb.jrc.ec.europa.eu/reference/lcp.html

Table 2. Average stack emission concentrations and pollutant mass flow rates at full plant operation under the BREF limits with weakened SO2 limit.

Stack	SO2, mg/Nm3	NOx, mg/Nm3	PM, mg/Nm3	Hg, µg/Nm3	SO2, g/s	NOx, g/s	PM, g/s	Hg, mg/s
K1	320	175	8	7	123.5	166.3	7.6	6.7
K2	320	175	8	7	123.5	166.3	7.6	6.7
K5,6	320	175	8	7	143.0	192.5	8.8	7.7
K7	320	175	8	7	84.5	113.8	5.2	4.6
K8	320	175	8	7	84.5	113.8	5.2	4.6

Table 3. Average stack emission concentrations and pollutant mass flow rates at full plant operation under the derogated limits.

Stack	SO2, mg/Nm3	NOx, mg/Nm3	PM, mg/Nm3	Hg, µg/Nm3	SO2, g/s	NOx, g/s	PM, g/s	Hg, mg/s
K1	570	175	8	30	541.5	166.3	7.6	28.5
K2	570	175	8	30	541.5	166.3	7.6	28.5
K5,6	475	175	8	30	522.5	192.5	8.8	33.0
K7	570	175	8	30	370.5	113.8	5.2	19.5
K8	570	175	8	30	370.5	113.8	5.2	19.5

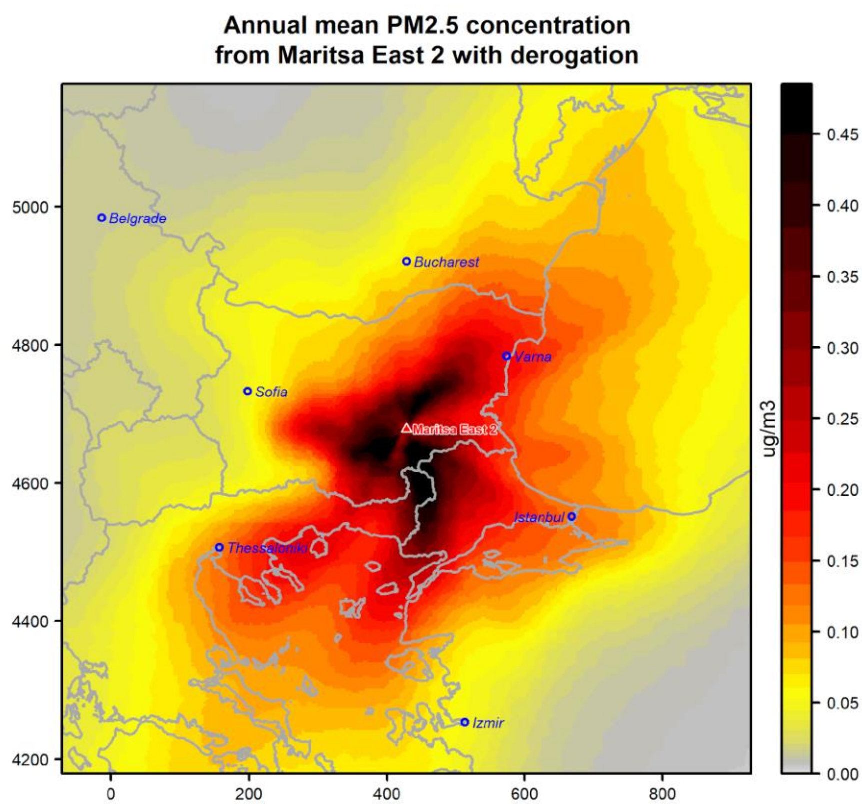
Average stack emission concentrations under the derogation were calculated on the basis of SO2 concentration of 19,000mg/Nm3 and minimum desulfurization rate of 97%, except 97.5% in the case of units 5 and 6. These emission rates represent the maximum allowed average emissions under each scenario.

To establish short-term maximum air quality impacts, these full-operation emission rates were modeled for a full year. Annual air quality impacts and health impacts are assessed assuming 6500 full-load hours per year, taken from the desulfurization cost estimates in the plant operator’s derogation application.

IMPACTS ON AIR QUALITY

The emissions from Maritsa East 2 affect air quality across all of Bulgaria, as well as in neighboring countries. The highest predicted daily average SO2 concentrations attributed to the plant exceed the EU air quality standard of 125µg/m^3 over an area of 70km^2 and a population of approximately 3,000 people. However, the worst affected area lacks air quality monitoring stations.

The emissions expose an estimated 1.3 million people to SO2 concentrations and 15,000 people to PM2.5 concentrations exceeding WHO 24-hour guidelines, before considering any other emission sources in the region. This exposure carries a significant risk of acute respiratory symptoms, especially for vulnerable groups such as children, elderly people and people with pre-existing respiratory ailments.



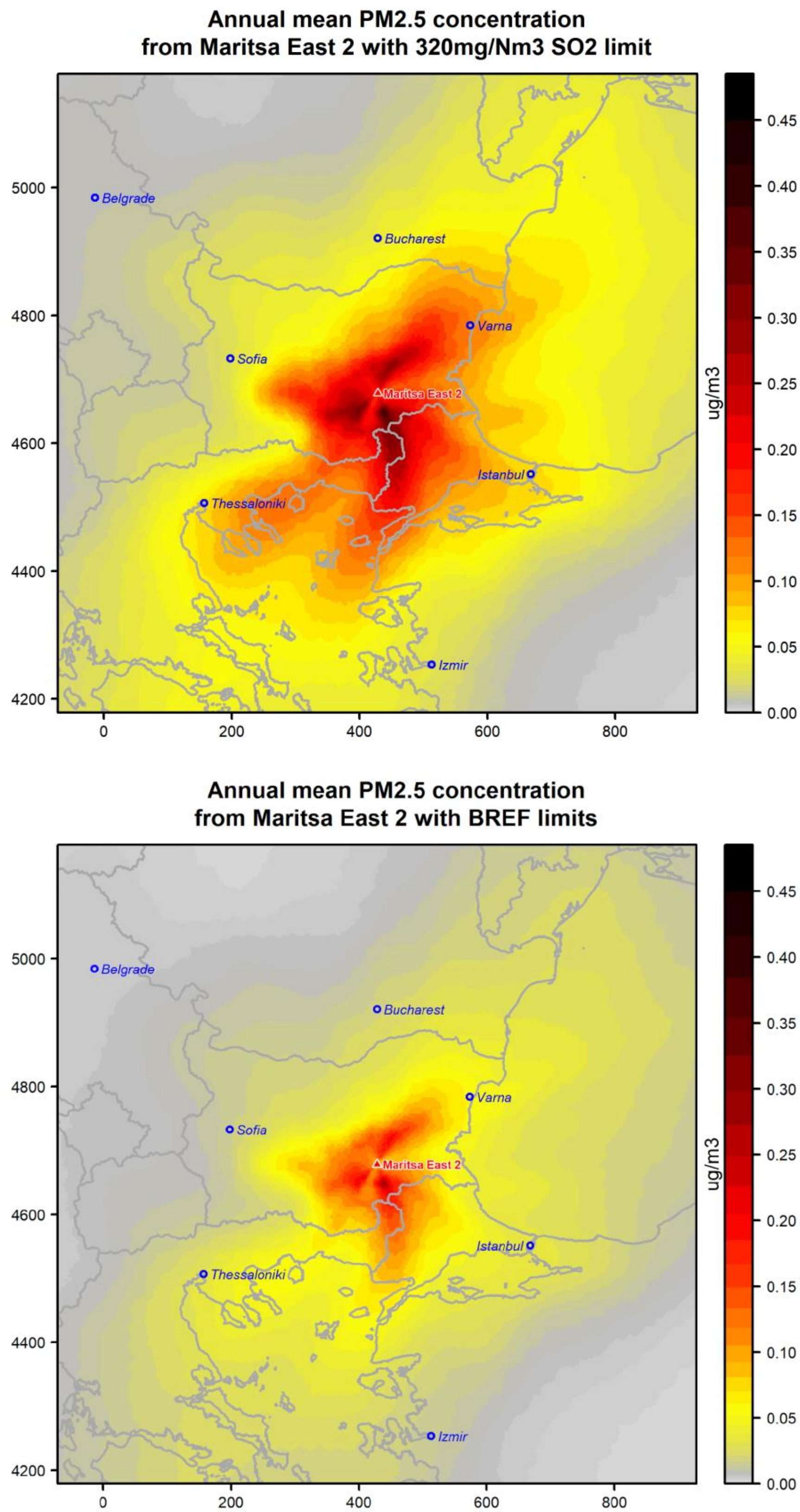
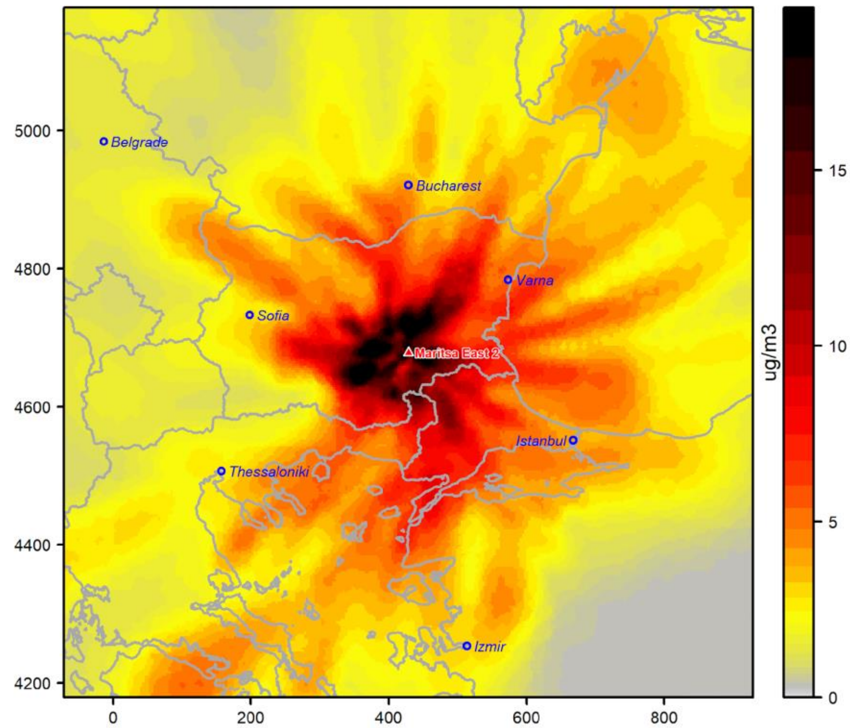


Figure 1 Projected annual average PM2.5 concentration attributable to emissions from the Maritsa East 2 power plant.

Maximum 24-hour PM2.5 concentration from Maritsa East 2 with derogation



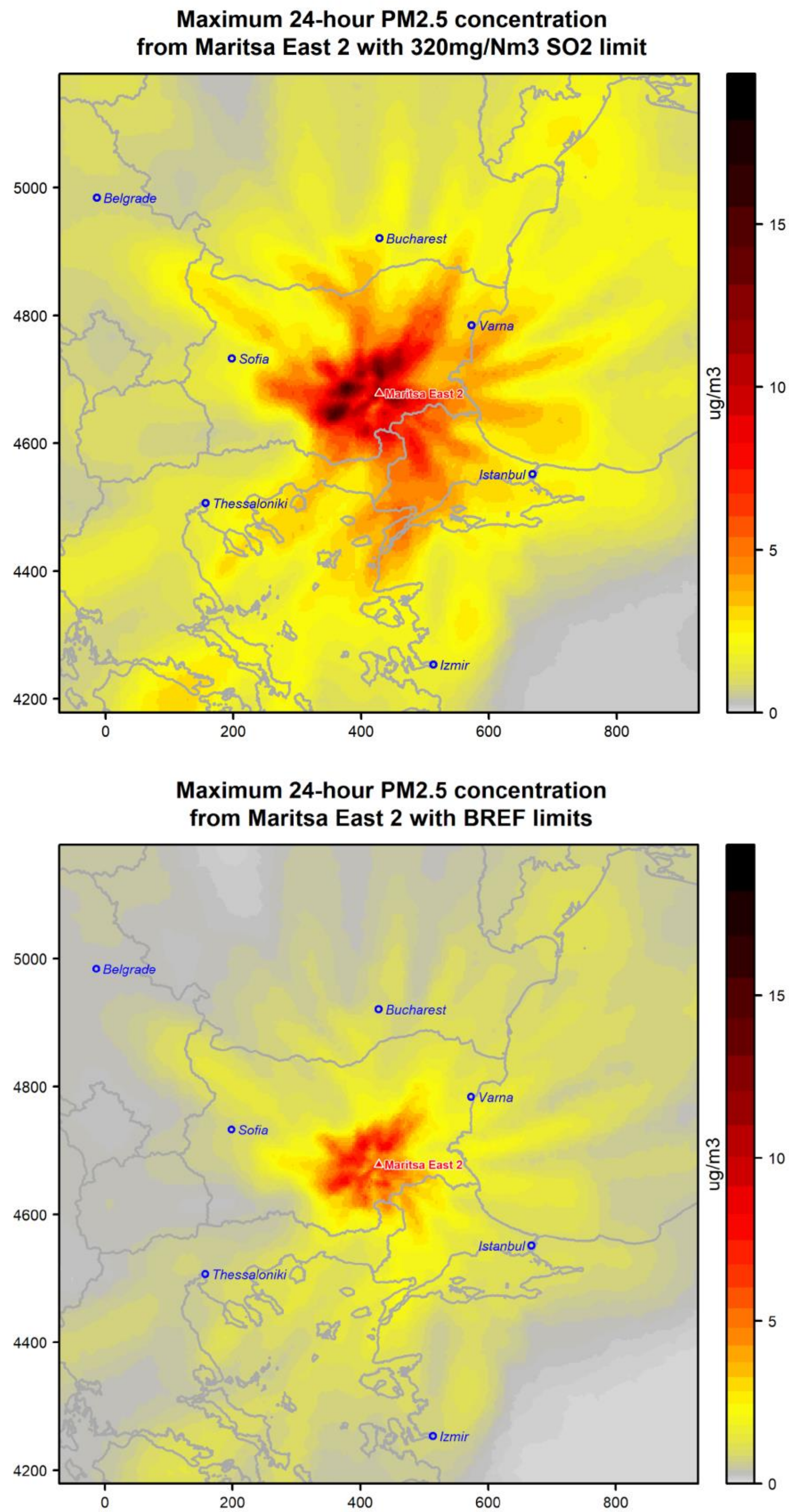
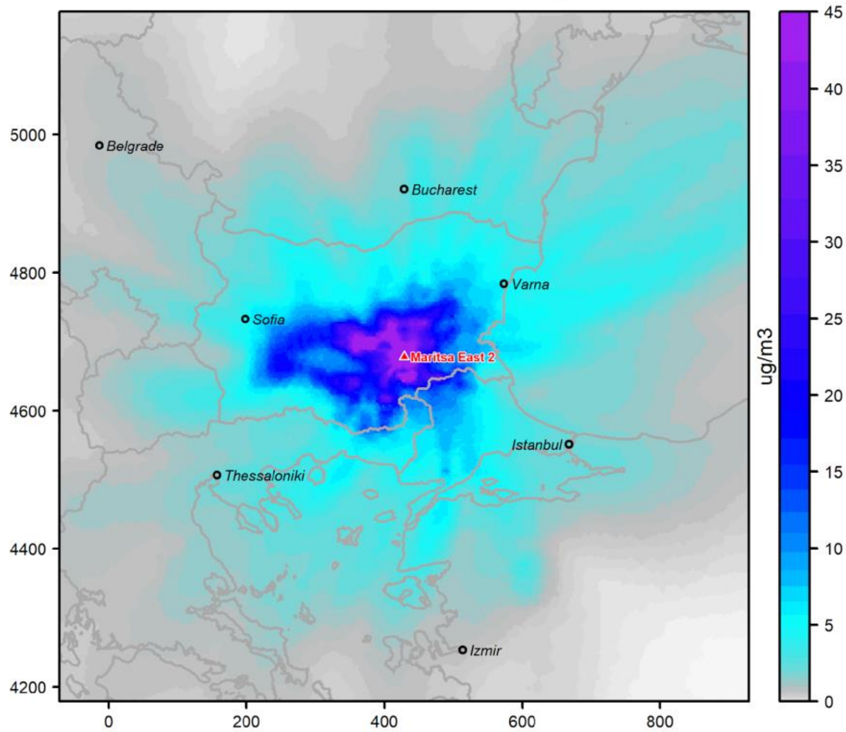
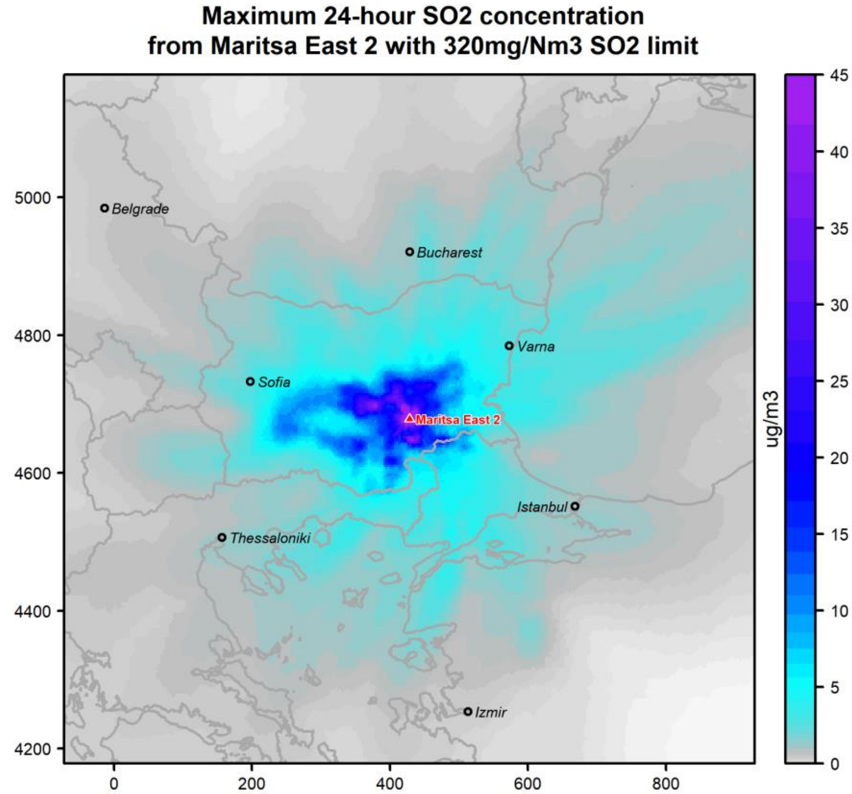


Figure 2 Projected maximum 24-hour PM2.5 concentration attributable to emissions from the Maritsa East 2 power plant.

Maximum 24-hour SO2 concentration from Maritsa East 2 with derogation





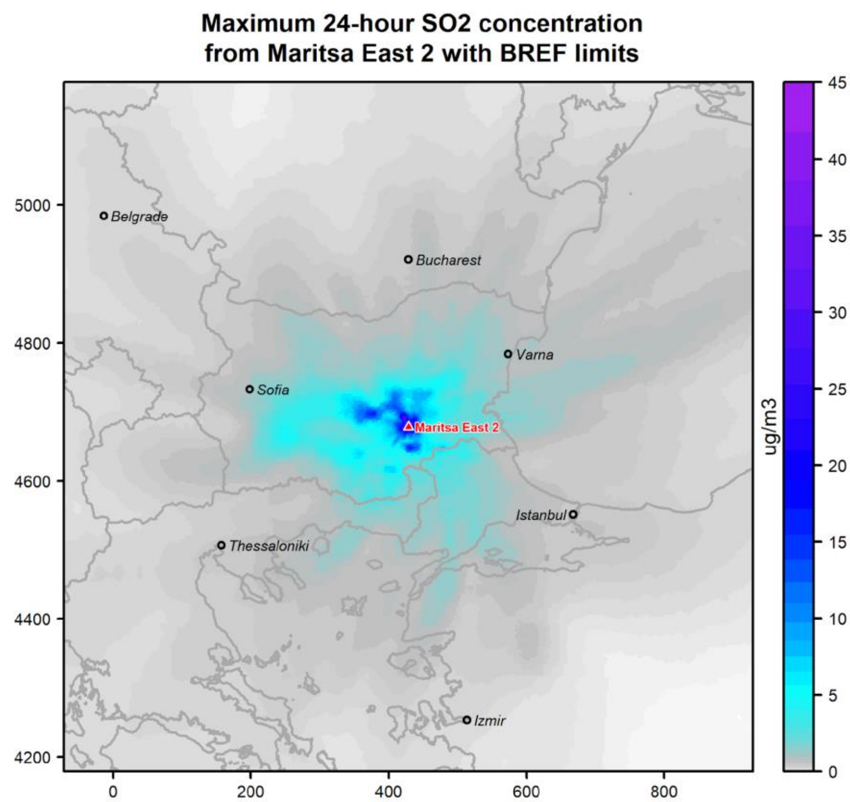


Figure 3 Projected maximum 24-hour SO2 concentration attributable to emissions from the Maritsa East 2 power plant.

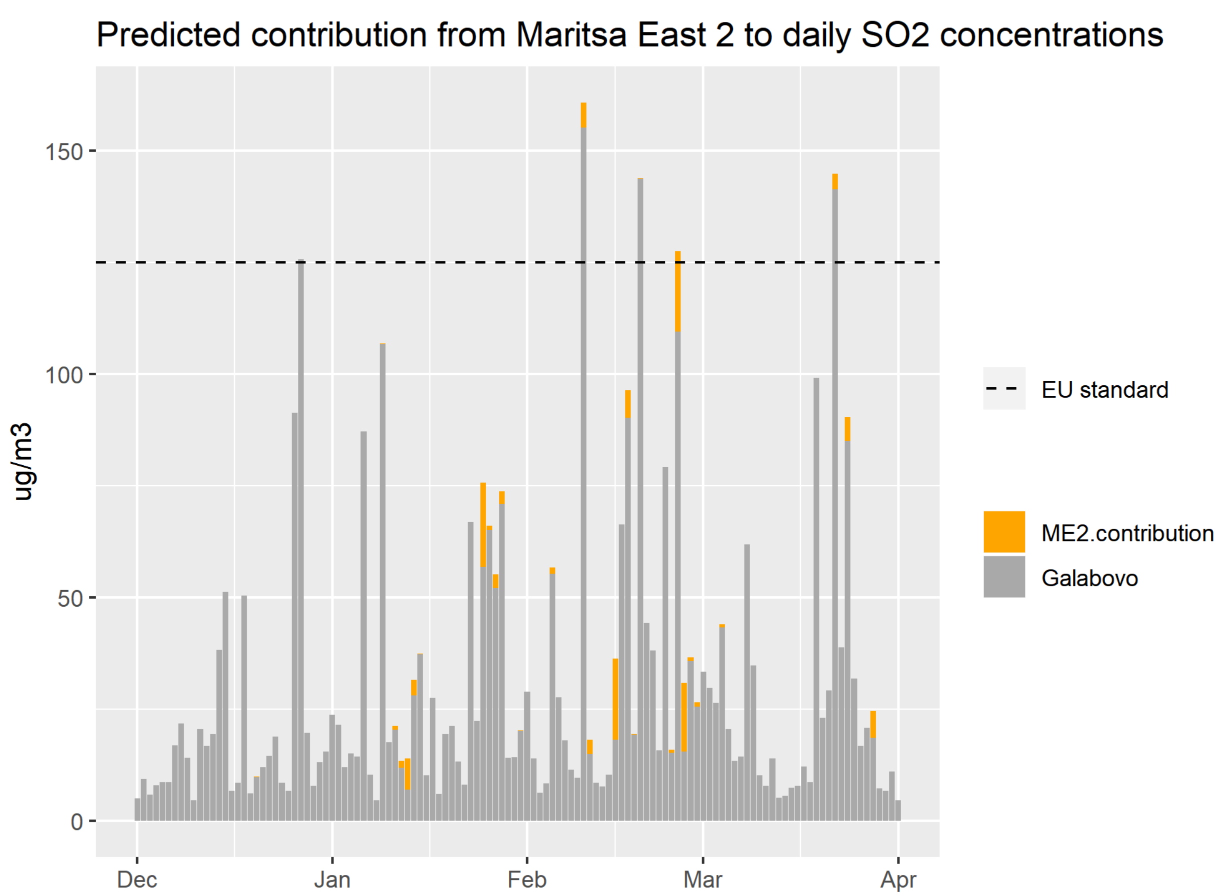
CUMULATIVE IMPACT WITH OTHER SOURCES

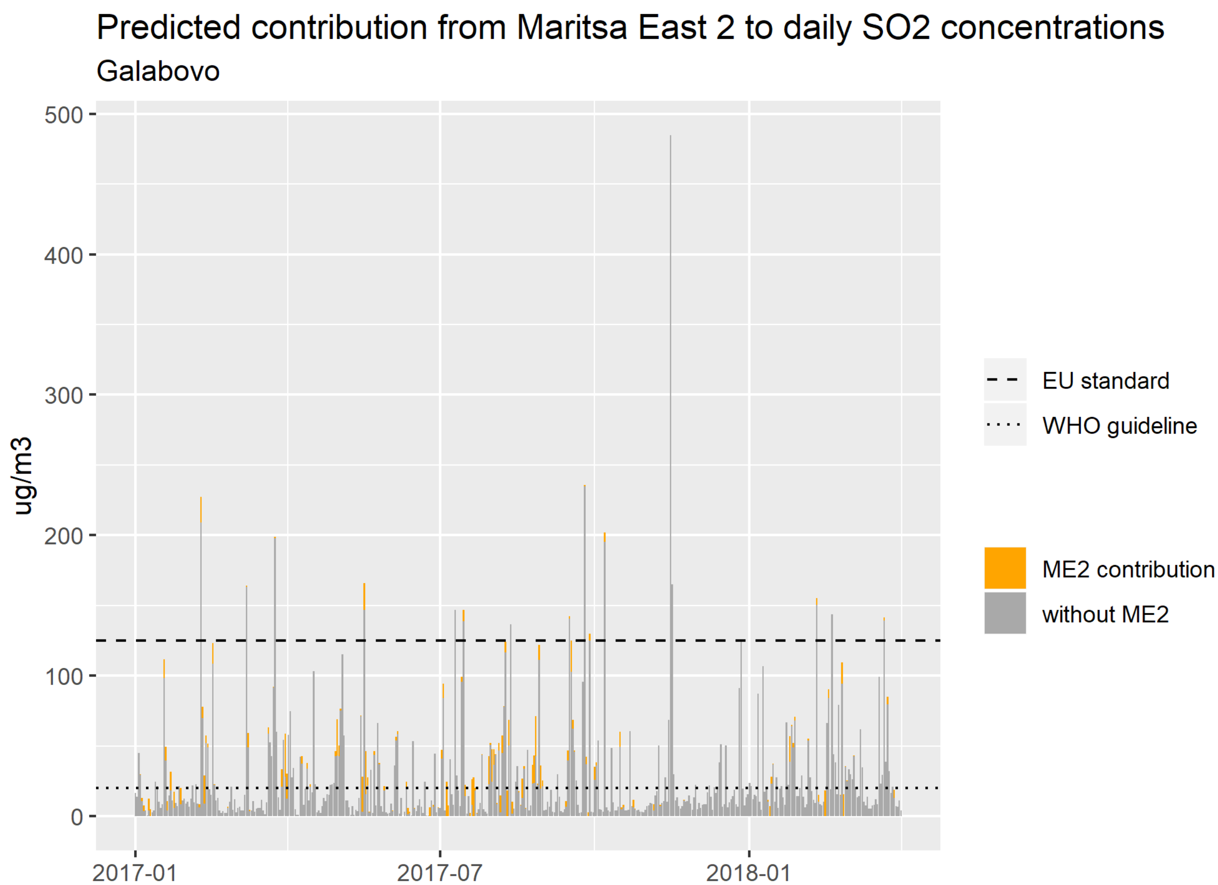
To assess the contribution of Maritsa East 2 to short term SO2 pollution peaks, daily concentrations predicted by the CALPUFF model to be caused by the plant were compared to monitoring data from Galabovo and three other cities. Out of these cities, Galabovo experiences frequent exceedances of the EU ambient air quality standard for 24-hour SO2 concentration set at 125 µg/m3; Dimitrovgrad had one exceedance and Stara Zagora and Kardjaly did not report exceedances of the legal limit. SO2 concentrations in all cities frequently exceed the World Health Organization guideline.

The largest predicted contribution from Maritsa East 2 under the derogated emission limits to daily average SO2 levels in Galabovo is 32ug/m3, 26% of the 24-hour air quality standard. Figure 6 shows the predicted contribution from the plant, day-to-day, for the Jan 2017 - Mar 2018 period for which monitoring data was available. Out of the four exceedances of the 24-hour limit, one exceedance would have likely been avoided without the emissions from the plant; and the plant contributed to 3 out of the four exceedances of the daily standard during this period which indicates that exceedances tend to take place when Maritsa East 2 is upwind of Galabovo.

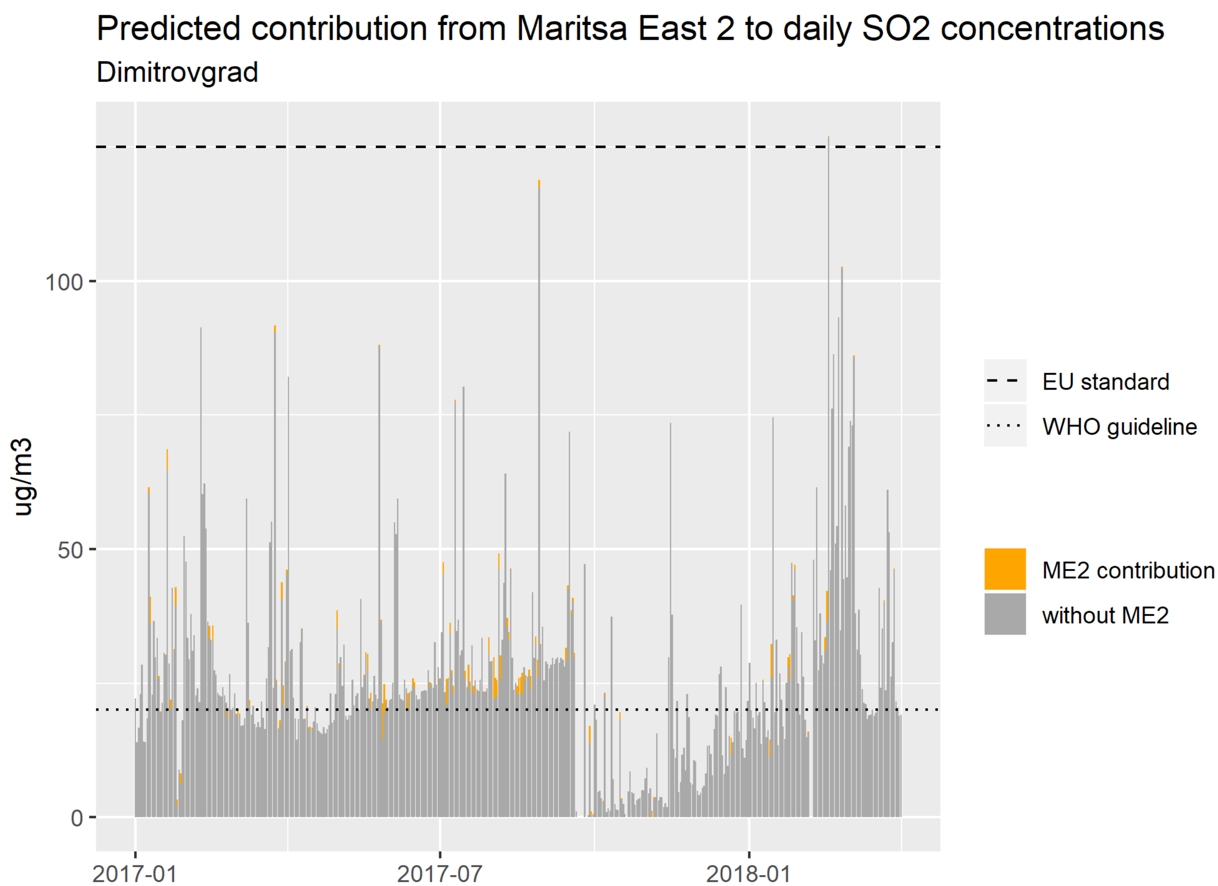
In Kardjaly and Stara Zagora, the largest contribution from the plant to SO2 concentrations exceeds 20ug/m3, substantially contributing to spikes in concentrations.

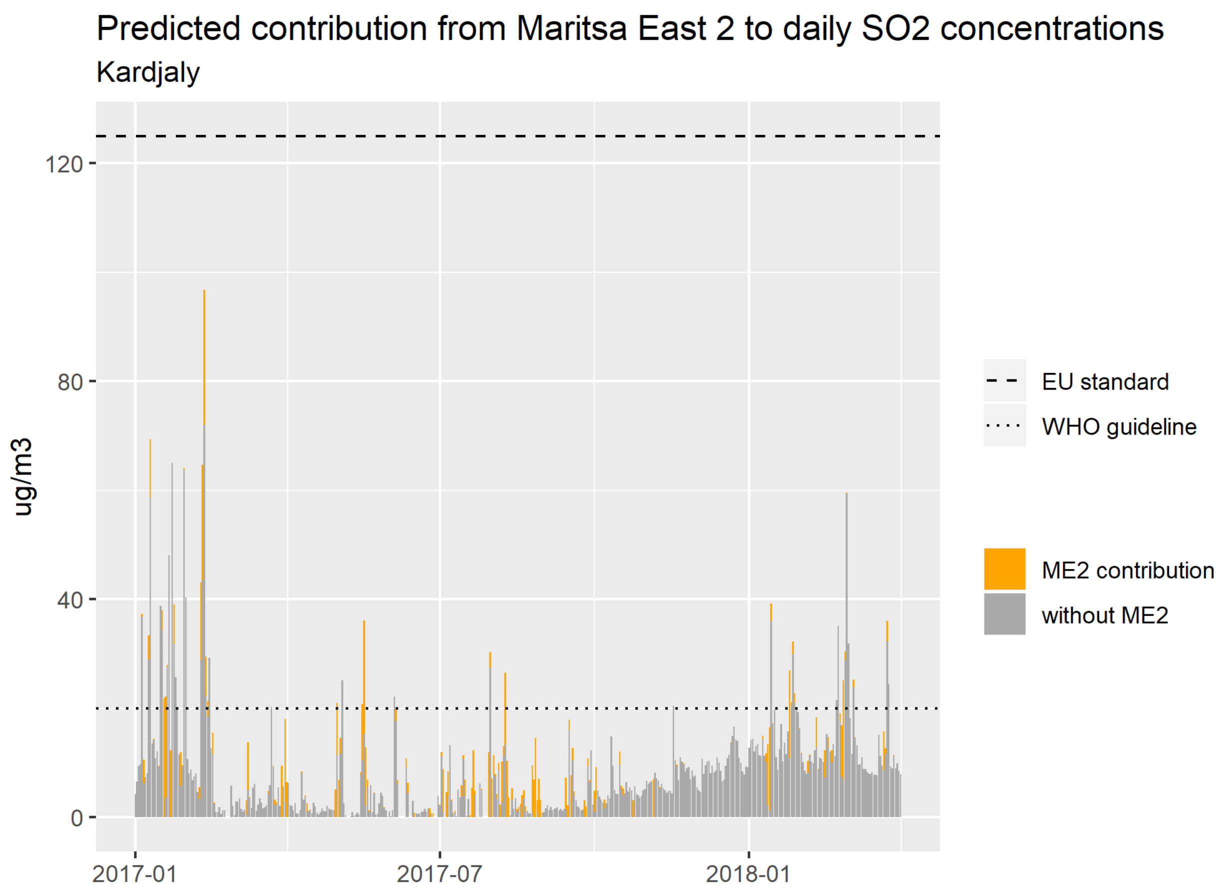
Monitoring data from Stara Zagora exhibits long, distinct periods of unnaturally stable concentration that is highly likely to be due to malfunction or other erroneous data (Figure 5).





Predicted contribution from Maritsa East 2 to daily SO2 concentrations
Galabovo
ug/m3
500
400
300
200
100
0
2017-01
2017-07
2018-01
EU standard
WHO guideline
ME2 contribution
without ME2


Predicted contribution from Maritsa East 2 to daily SO2 concentrations
Dimitrovgrad
ug/m3
100
50
0
2017-01
2017-07
2018-01
EU standard
WHO guideline
ME2 contribution
without ME2


Predicted contribution from Maritsa East 2 to daily SO2 concentrations
Kardjaly
120
80
40
0
ug/m3
2017-01
2017-07
2018-01
EU standard
WHO guideline
ME2 contribution
without ME2

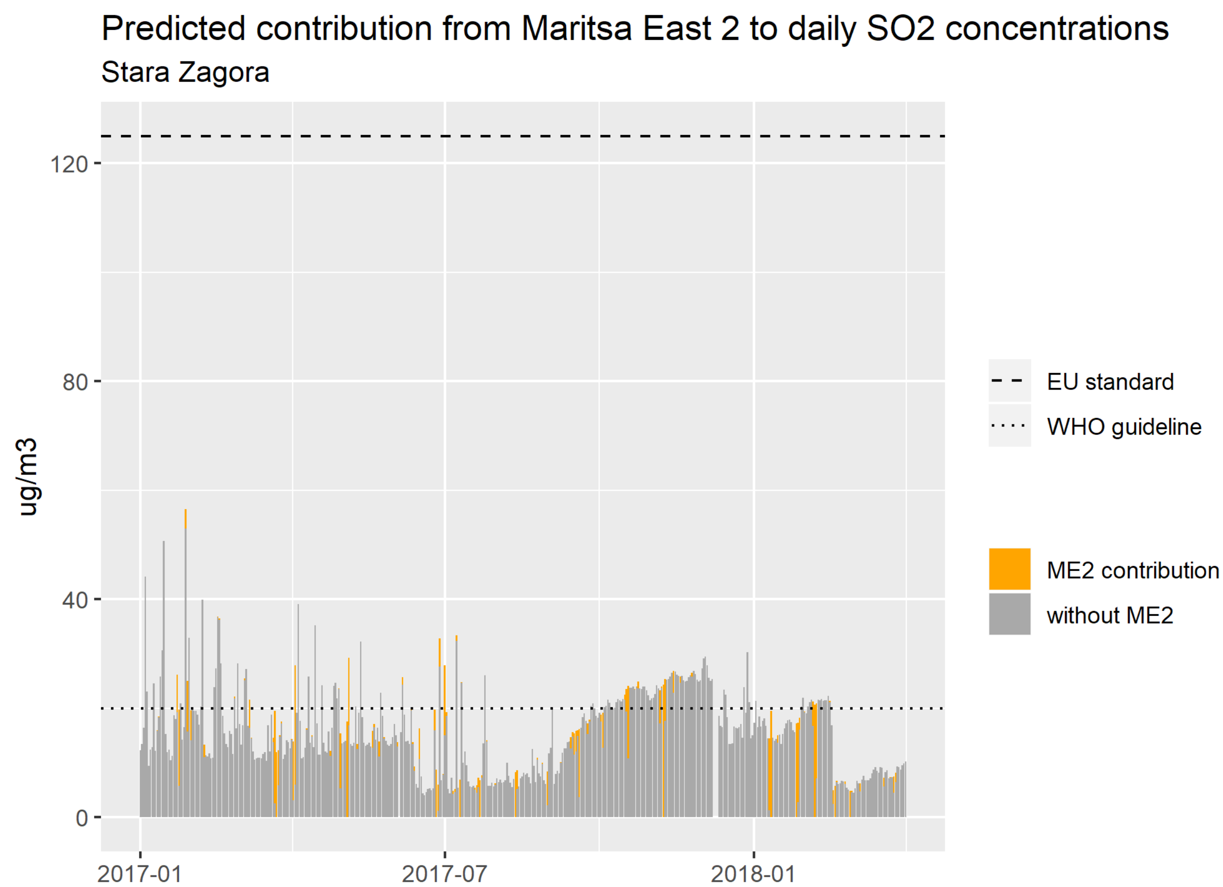


Figure 4. Measured daily average SO2 concentrations in four cities in Jan 2017 – Mar 2018 and predicted contribution from Maritsa East 2. The total height of the columns corresponds to concentrations measured in each of the four cities; the orange area corresponds to concentrations attributed to Maritsa East 2 while the gray area is attributed to other sources. On days that don't have an orange area, the predicted contribution from Maritsa East 2 at this specific station is too small to be displayed – the emissions plume does not reach the relevant city every day due to wind directions and other meteorological factors.

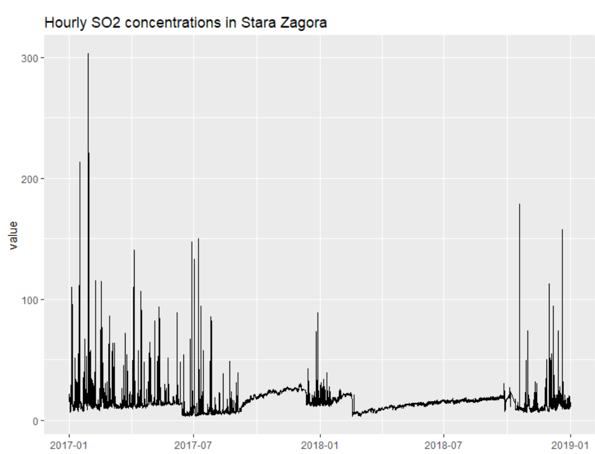


Figure 5. Hourly SO2 concentrations in Stara Zagora.

TRANSBOUNDARY IMPACT

Under the derogation scenario, emissions from the plant significantly impact air quality in Greece and Turkey, and to a lesser extent in Romania. Highest predicted contributions to daily average PM2.5 concentrations in Greece and Turkey exceed 15µg/m3, or 60% of the WHO guideline. Given the magnitude of the concentrations attributed to emissions from Maritsa East 2, it is likely that emissions from the plant contribute to exceedances of EU air quality standards and WHO norms in these countries.

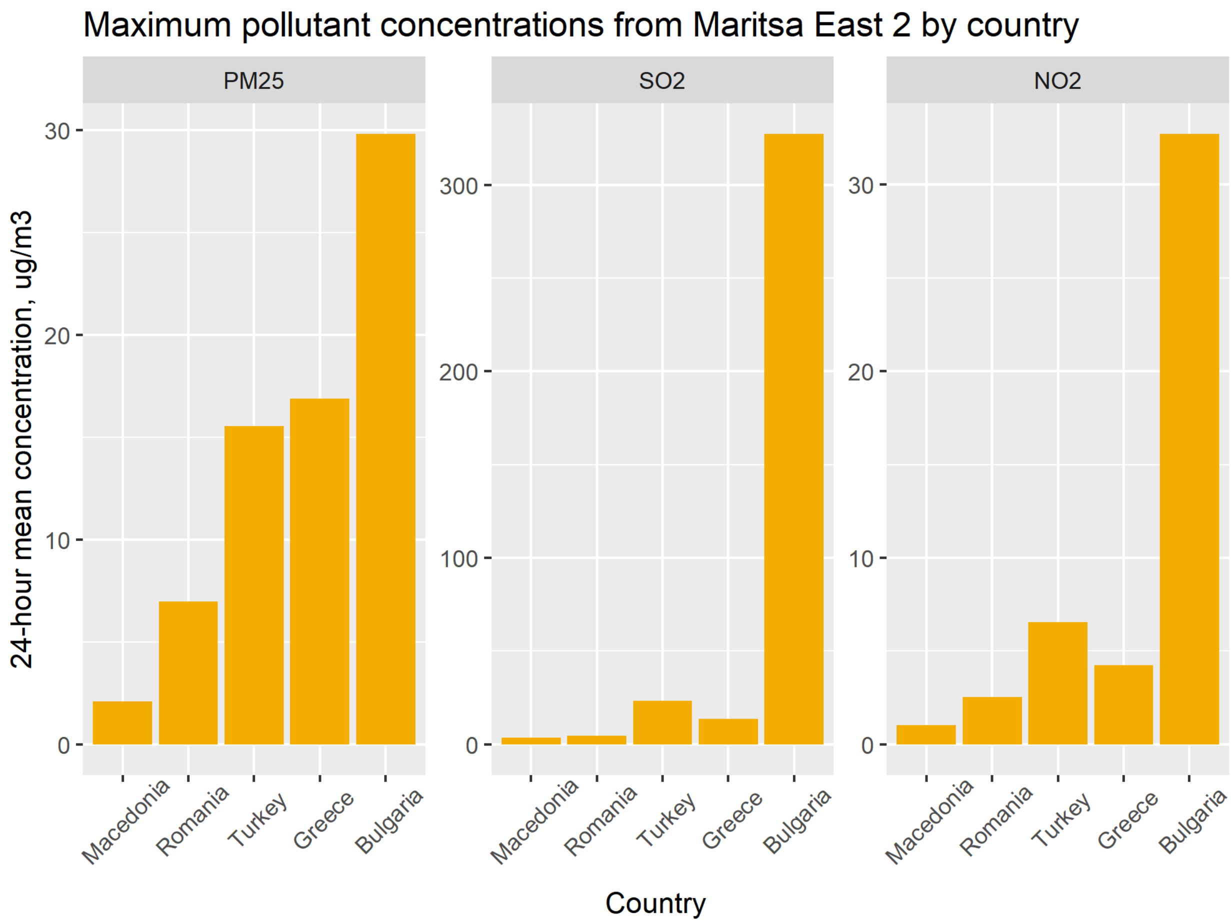


Figure 6 Projected maximum 24-hour pollutant concentrations attributable to emissions from the Maritsa East 2 power plant by country.

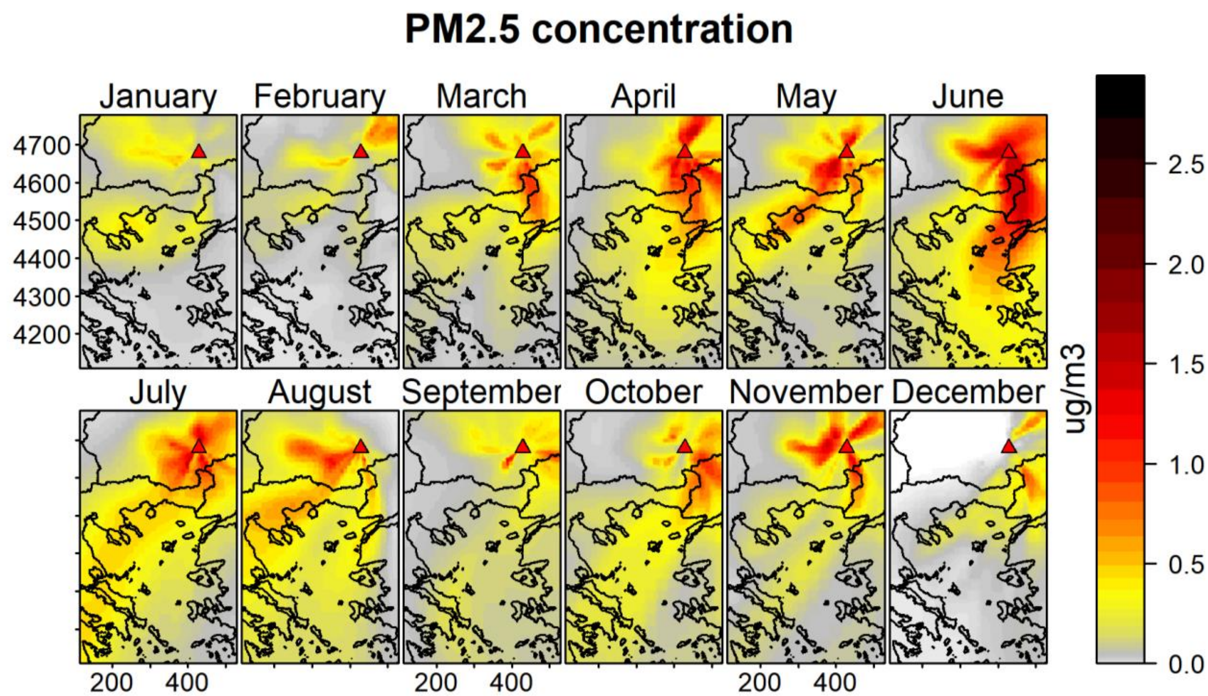


Figure 7 *Average monthly PM2.5 concentrations from the plant in 2017. Impact on Greece and Turkey is most pronounced during spring and summer months.*

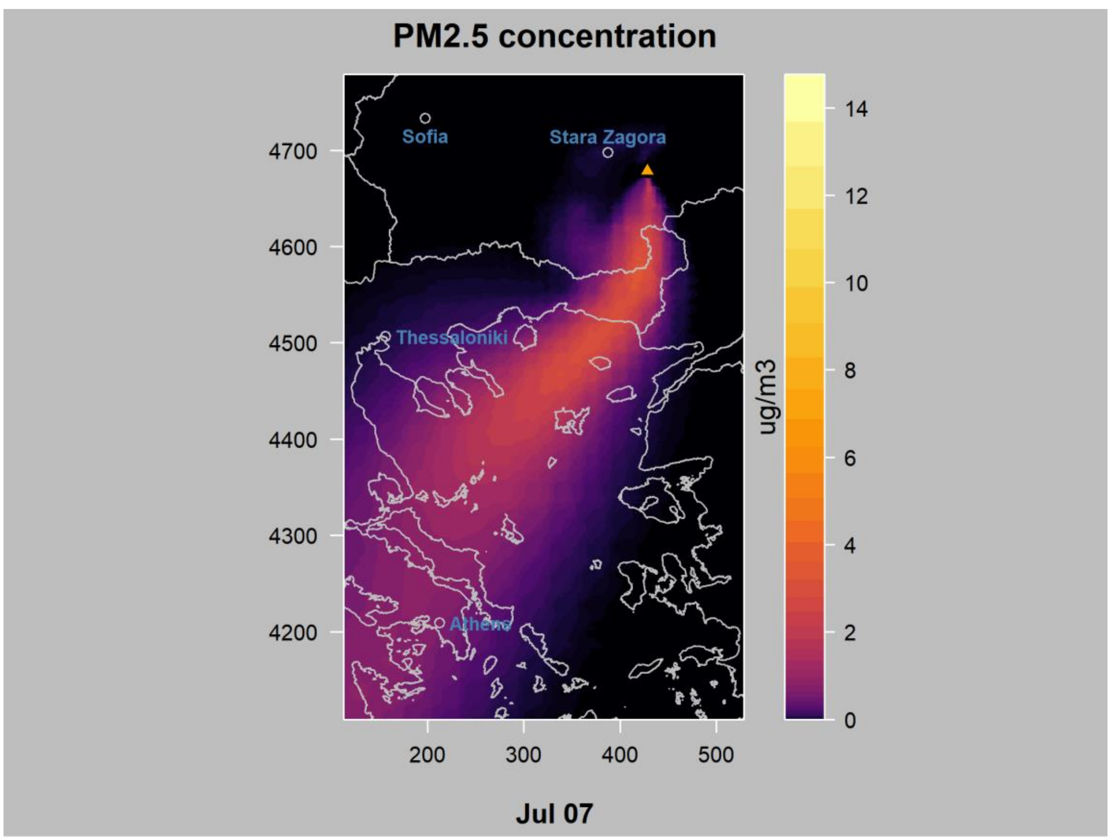


Figure 8 *An example of significant daily impact on air quality in Greece; conditions on Jul 7, 2017.*

HEALTH IMPACTS

The health impacts of emissions from the power plant were assessed in both scenarios by comparing health risks associated with pollutant exposure from the power plant with the situation in which this pollutant exposure is eliminated. The assessment was based on risk functions and methods recommended by the WHO for air pollution health impacts assessment in Europe as implemented and peer reviewed in Huscher et al (2017).

Due to the very large SO2 emissions from the plant, a key health impact pathway is the formation of secondary sulfate PM2.5 from SO2, which contributes to population exposure to PM2.5. This mechanism is modeled by the CALPUFF dispersion model. For the importance of the pathway see e.g. European Environment Agency's assessment of the costs of industrial air pollution in Europe, finding that exposure to secondary particles formed due to SO2 emissions is responsible for approximately two thirds of health costs (mainly stemming from premature deaths) caused by industrial air pollutant emissions (EEA 2014, Fig 3.5)[2].

Under the derogation scenario, Maritsa East 2 would be responsible for an estimated 420 premature deaths each year, or about 4,200 in total if the derogation is applied over a 10-year period. Approximately 2,700 of these premature deaths would be avoided if the plant complied with the BREF limits.

Other health impacts in the derogation scenario include 9,400 cases of asthma symptoms in children, 90 babies born with low birth weight, 190 new cases of chronic bronchitis and 360 hospital admissions.

If the emission SO2 limit is lowered to 320mg/Nm3, the plant would be responsible for an estimated 2,700 premature deaths over a 10-year period, avoiding approximately 1,500 deaths.

One quarter of the projected health impacts takes place in Bulgaria, with three quarters taking place in neighboring countries, with approximately 100 premature deaths per year in Bulgaria and Turkey, 60 in Romania and 50 in Greece. Over a 10-year period, 1,100 premature deaths would be avoided outside Bulgaria in the BREF limits scenario.

Table 4 Projected premature deaths and other health impacts caused by emissions from the studied power plant under the two emissions scenarios (cases per year).

Effect	Pollutant	Derogation scenario		320mg/Nm3 SO2 limit	
premature deaths	PM2.5	377	(246-500)	227	(148-301)
premature deaths	NO2	69	(39-99)	69	(39-99)
premature deaths	Total	423	(272-599)	273	(174-400)
low birth weight	PM2.5	93	(29-162)	56	(17-97)
asthmatic symptoms in children	PM10	9,367	(2029-16,873)	5,629	(1219-10,140)
chronic bronchitis in	PM10	192	(68-300)	115	(41-181)

[2] The health impacts of SO2 emissions quantified in the report are entirely due to formation of secondary pollutants - see p. 22: "The quantified health effects of SO2 , NOX, NH3 and NMVOCs result from the formation of secondary PM and ozone through chemical reactions in the atmosphere."

adults, new cases					
bronchitis in children	PM10	1,011	(-265-2,284)	607	(-159-1,372)
hospital admissions	NO2	44	(28-59)	44	(28-59)
hospital admissions	PM2.5	315	(13-617)	189	(8-371)
sickness days	PM2.5	646,314	(578,951-726,726)	388,329	(347,855-436,644)
lost working days	PM2.5	77,644	(66,052-89,160)	46,707	(39,733-53,634)

Table 5 Projected avoided premature deaths and other health impacts (cases per year) in the BREF limits scenario, compared to the derogation scenario.

		Derogation compared to 320mg/Nm3 SO2 limit	
Effect	Pollutant	Avoided cases per year	Reduction, percent
premature deaths	PM2.5	150	-40%
premature deaths	NO2	0	0%
premature deaths	Total	150	-36%
low birth weight	PM2.5	37	-40%
asthmatic symptoms in children	PM10	3,738	-40%
chronic bronchitis in adults	PM10	76	-40%
bronchitis in children	PM10	403	-40%
hospital admissions	NO2	-	0%
hospital admissions	PM2.5	126	-40%
sickness days	PM2.5	257,985	-40%
lost working days	PM2.5	30,938	-40%

Table 6 Projected premature deaths due to PM2.5 exposure in the three scenarios by country.

Country *Scenario:*	***Derogation***	***320mg/Nm3 SO2 limit***	***Difference (avoided deaths)***
Bulgaria	97	58	39
Total outside Bulgaria	280	169	111
of which:			
Turkey	99	59	40
Romania	57	34	22
Greece	52	31	21
Ukraine	37	22	14
Moldova	12	7	5
Others	24	15	9
Total	**377**	**227**	**150**

TOXIC FALLOUT

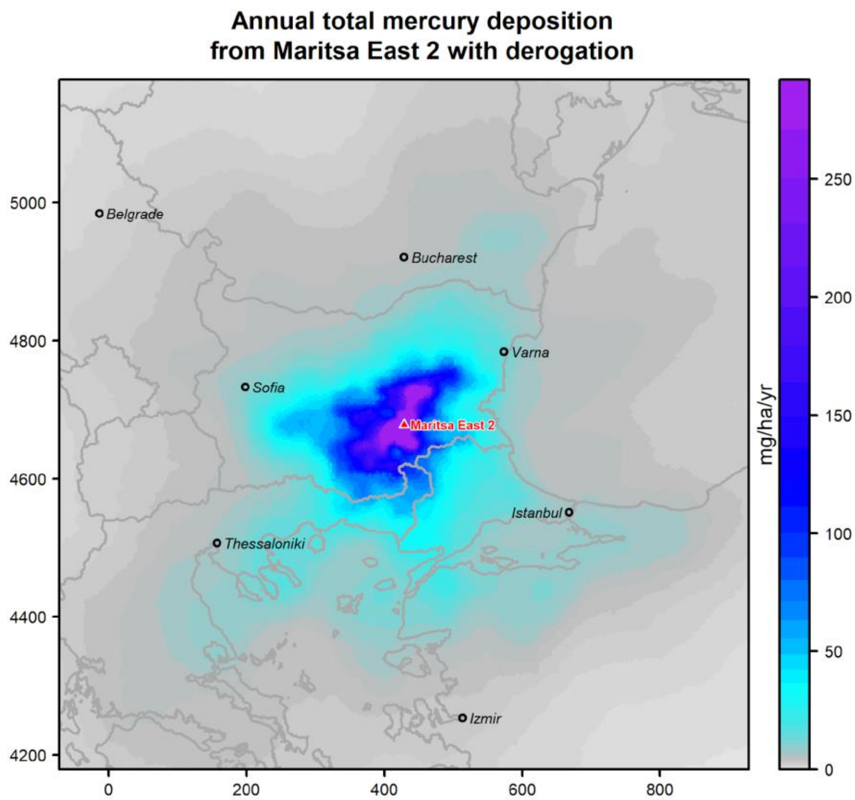
The pollution emissions from coal-fired power plants lead to deposition of toxic heavy metals, fly ash, acid rain and mercury (Figure 9, Figure 10 and Figure 11).

Of the estimated maximum mercury emissions of 3000kg/year allowed under the derogation, approximately 930kg or 23% would be deposited into land ecosystems within the modeling domain. Mercury deposition rates as low as 125mg/ha/year can lead to accumulation of unsafe levels of mercury in fish (Swain et al 1992). Under the maximum emissions allowed under the derogation, the plant is estimated to cause mercury deposition above 125mg/ha/yr over an area of approximately 10,000km2, with a population of 1.0 million people (Figure 9).

Approximately 50% of mercury deposition would take place onto forested land and 30% onto cropland.

While actual mercury uptake and biomagnification depends very strongly on local chemistry, hydrology and biology, the predicted mercury deposition rates are a cause for serious concern.

Annual total mercury deposition from Maritsa East 2 with derogation



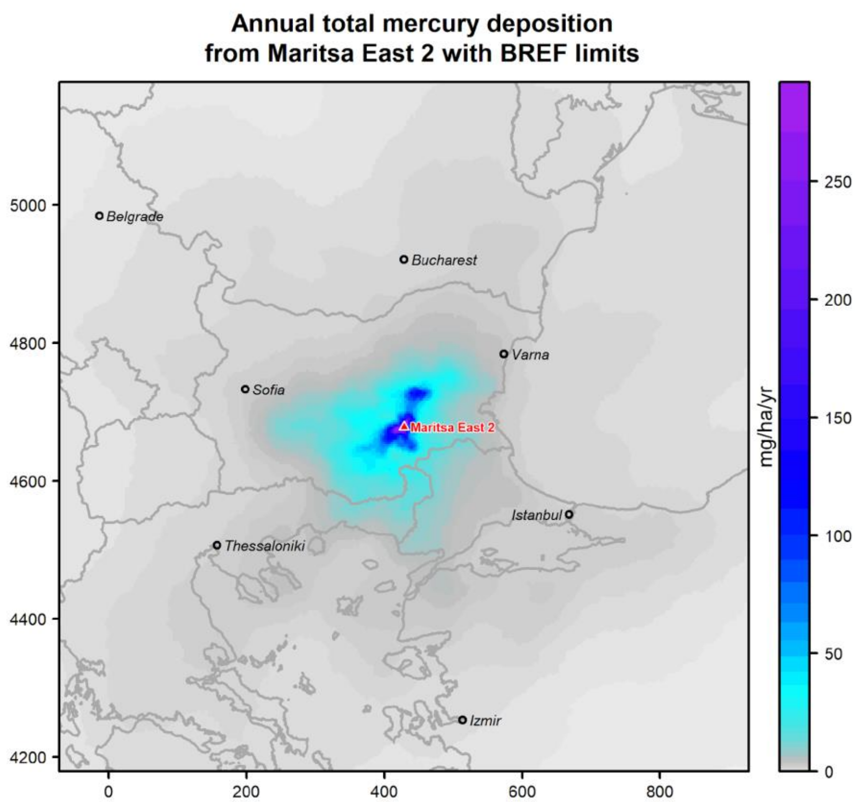
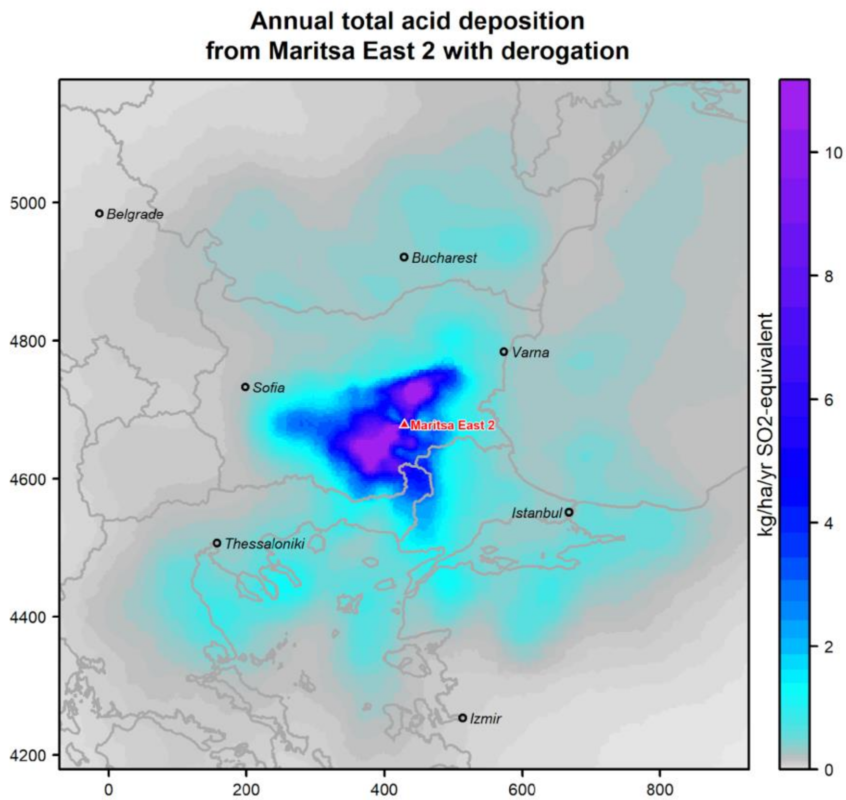


Figure 9 Projected mercury deposition from the Maritsa East 2 power plant.



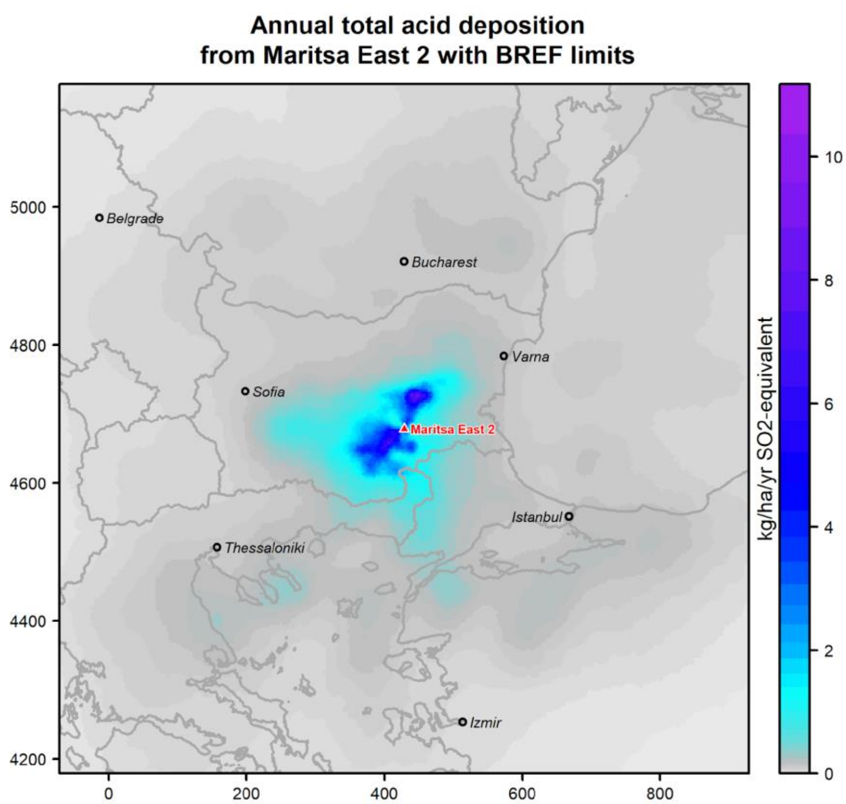


Figure 10 Projected acid deposition (SO2 equivalent) from the Maritsa East 2 power plant.

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APPENDIX: MATERIALS AND METHODS

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.

The choice of the CALPUFF model for this assessment was based on the need to assess pollutant transport beyond the distances that are appropriate for AERMOD, that is beyond 50km, its suitability for assessing point source contributions to pollutant levels, detailed modeling of plume rise and ability to obtain results at a high spatial resolution, as well as the need to take into account chemical transformation of pollutants in the atmosphere which is not possible with plume models such as AERMOD. CALPUFF is the most widely used model for these applications, and overall the most commonly used model for regulatory purposes related to thermal power plants after AERMOD and ISC type plume models. CALPUFF is differentiated from gridded chemical-transport models such as CMAQ, CAMx and EMEP MSC-W by its high spatial resolution and ability to model single source contributions without the need to develop a detailed emission inventory for the entire modeling domain, a major undertaking which would not have been feasible within the timeframe of this study.

The CALMET/CALPUFF modeling system has been identified by European Topic Centre on Air Pollution and Climate Change Mitigation as a model that may be used for air quality assessment and planning relevant to the European Air Quality Directive (Denby 2011). It has been used for assessing source contributions, including source contributions from thermal power plants, to ambient air pollution in Milan and Paris (Castell et al 2013). The model has been validated and used for modeling overall air quality and source contributions to air pollutant levels on the regional scale in Warsaw, Poland (Holnicki et al 2015 and 2017).

Simulations were carried out for the period Dec 31, 2016 to Apr 1, 2018. All concentration and health impact results are reported for the calendar year 2017, except for the cumulative impacts analysis for Galabovo which was carried out for the period Dec 1, 2017 to Mar 31, 2018 due to availability of air quality monitoring data.

Meteorological data for the simulations was generated using the TAPM modeling system, developed by Australia's national science agency CSIRO, and cross-validated against the observational data. TAPM uses as its inputs global weather data from the GASP model of the Australian Bureau of Meteorology, combined with higher-resolution terrain data. 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 set of nested grids with a 50x50 grid size and 30km, 10km and 5km horizontal resolutions and 12 vertical levels was used, centered on the power plant. U.S. EPA standard default model settings were used throughout. Deposition parameters for mercury, for which there is no default, were based on U.S. EPA (1997).

For emissions from main boilers of the power plants, 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.

Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA II chemistry module within CALPUFF, and required data on ambient ozone levels was processed from measurements reported by the Turkish government to the European Environmental Agency. Other required atmospheric chemistry parameters (monthly average ammonia and H2O2 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, NO2, NO3 and HNO3) based on background ammonia concentrations.

Local mercury deposition depends strongly on the speciation of mercury – how much of the mercury is emitted in divalent form (Hg2+), elemental gaseous form and bound to particles. The divalent form is most easily deposited locally. Average distribution of the different species with flue gas desulfurization reported by Lee et al. (2006) were used.

The health impacts resulting from the increase in PM2.5 concentrations were evaluated by assessing the resulting population exposure, based on high-resolution gridded population data for 2015 from NASA SEDAC (CIESIN, FAO and CIAT 2016), and then applying the health impact assessment recommendations of WHO HRAPIE (2013) and increase in low birth weight births based on Dadwand et al (2013). Baseline incidence and prevalence data for Bulgaria and neighboring countries were obtained from WHO Global Health Estimates (2014), birth rates and incidence of low birth weight from World Bank (undated).

Table 7 Risk ratios used for health impact assessment.

Effect	Pollutant	Central	Low	High
bronchitis in children	PM10	1.08	0.98	1.19
asthma symptoms in asthmatic children	PM10	1.028	1.006	1.051
incidence of chronic bronchitis in adults	PM10	1.117	1.04	1.189
long-term mortality, all causes	PM25	1.062	1.04	1.083
cardiovascular hospital admissions	PM25	1.0091	1.0017	1.0166
respiratory hospital admissions	PM25	1.019	0.9982	1.0402
restricted activity days	PM25	1.047	1.042	1.053
work days lost	PM25	1.046	1.039	1.053
bronchitic symptoms in asthmatic children	NO2	1.021	0.99	1.06
respiratory hospital admissions	NO2	1.018	1.0115	1.0245
long term mortality, all causes[3]	NO2	1.055	1.031	1.08
respiratory hospital admissions	NO2	1.0015	0.9992	1.0038
low birth weight	PM25	1.1	1.03	1.18

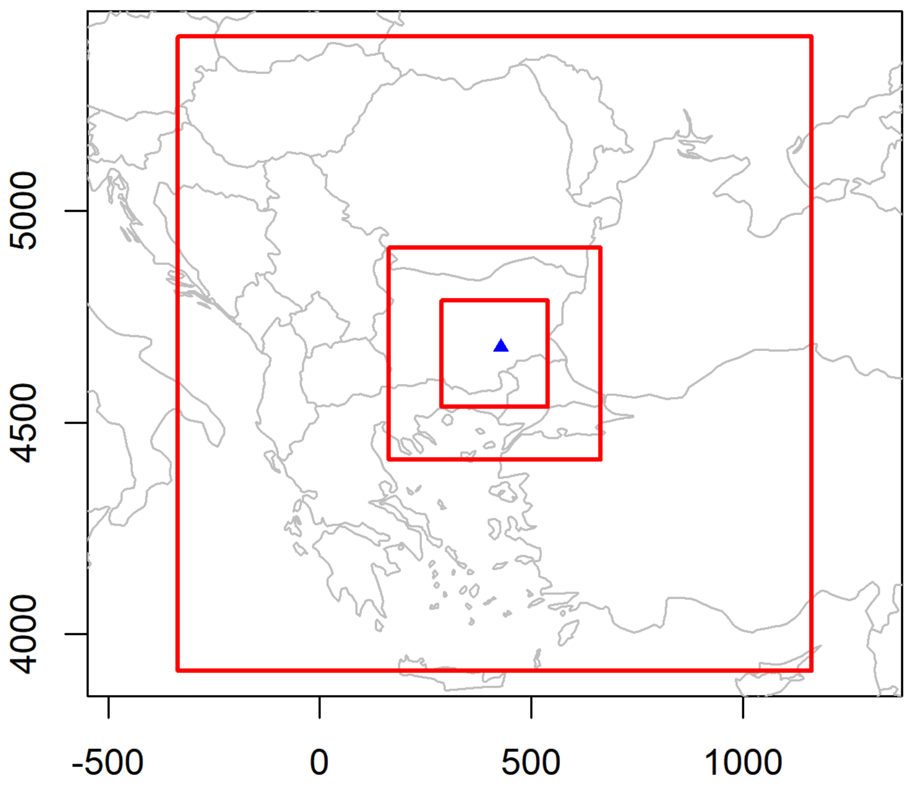

Figure 11 Calpuff modeling domains (red) and location of the studied power plant (blue triangle).

[3] To avoid the possible overlap identified with PM2.5 mortality impacts identified by WHO (2013), 2/3 of the NO2 mortality is included in the central estimates of total premature deaths, as well as in the low end of the confidence intervals, while the full mortality is included in the high end of the confidence interval.