Assessing the air quality, toxic and health impacts of the Mugla coal-fired power plants

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Summary

The Mugla (Milas and Yatagan) area in southwest Turkey is one of the largest concentrations of operating coal-fired power plants in the country, housing three power complexes. These coal-fired power plants are major point sources of air pollution in a relatively densely populated area of Turkey, with a large population of both domestic and international tourists in the summer. The large volume of pollutant emissions has 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 existing power plants in the region, combining detailed atmospheric modeling with existing epidemiological data and literature.

The emissions from the studied power plants elevate the levels of toxic particles and NO_2 in the air over the Mugla province and beyond, increasing 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. SO_2, NOx and dust emissions contribute to toxic particle exposure. Emissions from the plants cause acid rain, which can affect crops and soils, as well as fallout of toxic heavy metals such as arsenic, nickel, chrome, lead and mercury.

The current emissions from the coal-fired power plants are likely to result in an estimated 280 premature deaths and 100 low birth weight births per year due to exposure to PM2.5 and NO2, estimated based on 2015 and 2008 data on TPPs. Other impacts include 140 new cases per year of chronic bronchitis in adults, 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.

The emissions from the studied power plants expose an estimated 510,000 people to NO2 concentrations and 80,000 people to SO2 concentrations exceeding WHO 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. People living in the most affected locations are at a risk of severe acute health damage.

The pollution emissions from the power plants lead to deposition of toxic heavy metals, fly ash, acid rain and mercury. The plants are estimated to cause potentially unsafe levels of mercury deposition over a large area approximately 130 km across, with a population of 80,000 people.

Approximately 53% of the PM2.5 exposure and 25% of the NO2 exposure to populations attributed to the power plants takes place outside of Turkey, with the largest transboundary impact taking place in Egypt, followed by Israel, Greece and Palestine.

While public health impacts outside of Turkey are the largest in Egypt, due to the large exposed population, the largest increases in air pollutant concentrations outside of Turkey take place on Rhodes and other Dodecanese islands, likely contributing to violations of air quality standards on the islands.

During the entire operating life from commissioning to the end of 2017, the three power plants have been responsible for an estimated 45,000 premature deaths. A further 5,300 premature deaths are projected to occur if each plant continues to operate until it reaches a 50 year operating life.

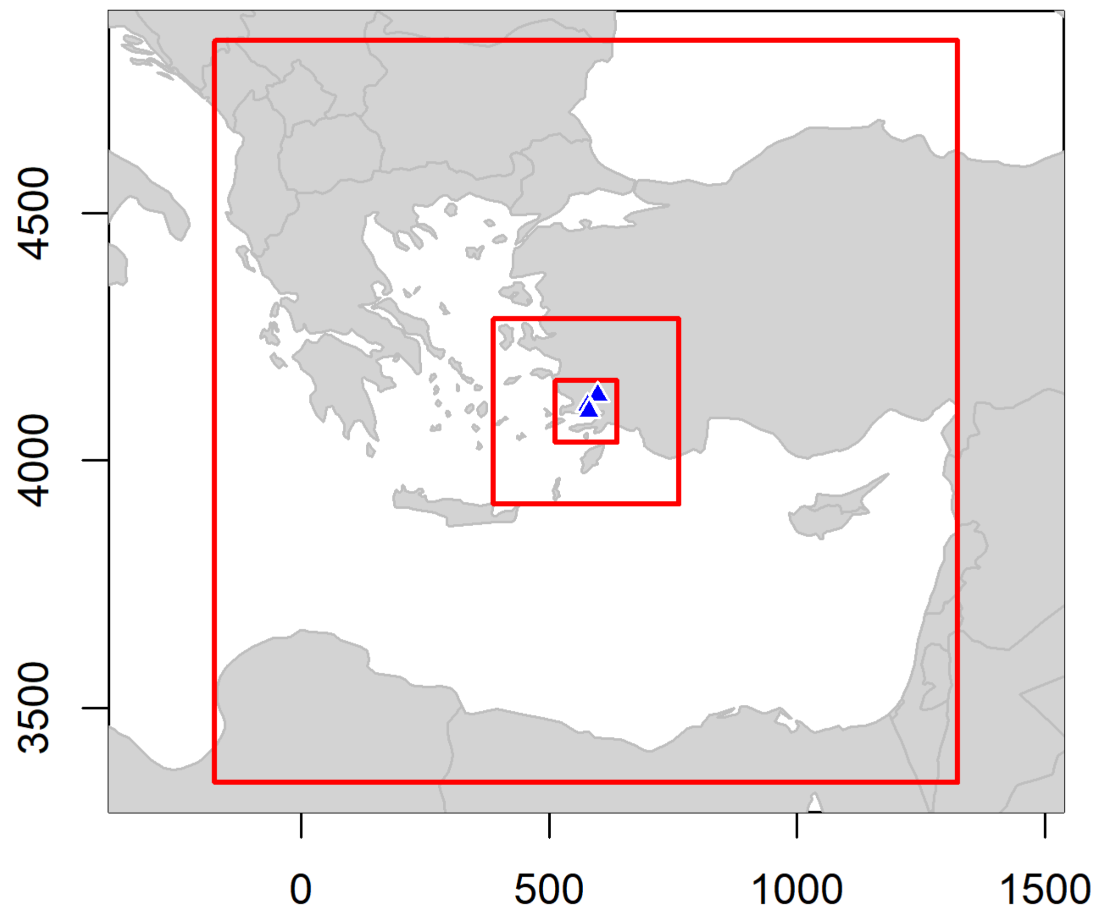

Figure 1 Calpuff modeling domains (red) and location of the studied power plants (blue triangles).

Air pollutant emissions

Current emissions of major air pollutants

Access to recent emissions data for the power plants is alarmingly limited, especially after the privatization of the power plants. Data on emission rates in grams per second from each stack was obtained from the Ministry of Environment and Urbanization (2017) for Kemerköy and Yenikoy for this study. However, annual total emissions volumes are not reported, and the reported emissions rates are based on three manual samples for each plant, not comprehensive continuous emission monitoring data, which means that periods of high emissions could be excluded. Furthermore, the data is not reported on routine or regular basis and it is not clear whether it fully reflects the current situation. Data for Yatagan was obtained from Güven et al (2007), and suffers from similar shortcomings. Data on mercury emissions was missing completely.

Amount of air pollutant, toxic and CO_2 emissions emitted from power plants is a matter of major public interest. The international best practice is to monitor emissions continuously and disclose emissions rates on hourly basis and emissions volumes at least annually; the level of information disclosure at the studied plants falls far behind this best practice.

The emission data used for the study includes both emissions from the main boilers of the power plants and from secondary sources such as auxiliary boilers and venting stacks.

Typical capacity factors of the main boilers were estimated by taking the average factors for each plant for 2010-2014, excluding years when each plant was undergoing retrofits. **Since there was no data on operating rates of the secondary sources (the fraction of time that each source is emitting), these sources were excluded from estimates of annual average air quality impacts**. Two scenarios were prepared: short-term air quality impacts were projected by modeling a situation in which all sources are emitting simultaneously at full rate; annual average air quality impacts were projected conservatively, assuming that secondary sources are not emitting at all, and main boilers are **emitting at their annual average rate (emission rate at full operation multiplied by operating rate).**

The power plant and emission data shown in Tables 1, 2 and 3 in Appendix 1 were used as the basis of modeling the plants' air quality impacts using the CALMET-CALPUFF modeling system. The modeling domains used are shown in Figure 1 above.

Reported emissions levels of the power plants in the region are extremely high in relation to their size, implying poor emissions control performance, which exacerbates their air quality and health impacts. For example, the SO_2, NOx and dust emission levels of the Yatagan power plant are 3-10 times as high as allowed in many other countries, including China and European Union[1]. (See Figure 3.) The situation could have improved in recent years but there was no validated emission data to show whether this is the case.

[1] Pollutant flue gas concentrations of the Yatagan power plant were estimated based on reported emissions rates and maximum flue gas flow of 1.45 mln Nm3/h on wet basis, assuming 30% of flue gas is water vapor.

Mercury emissions

Because no data was available on mercury emissions, the UNEP Mercury Toolkit (UNEP 2017) methodology was used to estimate these emissions. Data on the mercury content of Mugla-Yatagan lignites was obtained from the USGS World Coal Quality Inventory, and annual coal consumption and technology-specific default mercury capture rates were assumed.

Historic and future emissions

In addition to the current situation, we assessed the historical emissions from the power plants. All plants installed flue gas desulfurization (FGD) during the last decade. SO2 emissions before the installation of FGD was calculated from lignite sulfur content obtained from Turkish Chamber of Mining Engineers (UCTEA, 2015, 85). In addition, the FGD installation was assumed to have resulted in a 30% reduction in particulate matter emissions, and PM emissions for the period preceding the installation were calculated accordingly.

Data on annual lignite consumption by year at each power plant since beginning of operation until the end of 2017 was compiled from various sources[2]. Combined with data on plant heat rates and calorific value of the lignites, this information was used to calculate average utilization by year.

Further retrofits planned as a part of the Turkish-German Twinning Project on regulation of large combustion plants (TR-03-EN-01), if implemented, could reduce emissions compared with the current situation. Target flue gas concentrations of pollutants for these investments were indicated in an investment plan prepared as a part of the project (BMU 2006). Current flue gas concentrations corresponding to the emission rates reported for each plant were estimated by calculating the specific flue gas volume per energy input for the lignites. Specific flue gas volume was calculated using the empirical formula in European standard EN 12952-15 (p. 85, formula A.5N) based on calorific value, moisture and ash content. The specific flue gas volumes were used to estimate current flue gas concentrations at the plants:

$$FGC = ER / (CC * CAP * FGV),$$

where ER is the emissions rate in kg/h in full operation; CC is the design coal consumption rate (kg/MWh), CAP is the generating capacity of the plant (MW) and FGV is the specific flue gas volume (m3/kg).

If these current concentrations were higher than the target values indicated for the retrofit investments, emission rates were assumed to fall accordingly in the future to meet the new target values. To project future emissions from the plants, operating rates were assumed to stay at current (2015-17) average

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[2] For Yatagan (1983-1987); Yenikoy (1986-87) and Kemerkoy (1994-1995): Estimated values using coal consumption design values from UCTEA (2017) and gross generation figures of the corresponding years from EUAS Privatization and Power Plants Pursuance Department Annual Report, 2014. For Yatagan (1988-2009), Yenikoy (1988-2009) and Kemerkoy (1996-2009) data directly from: Turkish Coal Enterprises (TKI) (personal correspondence). For the years 2010-2014 data taken directly from: Electricity Generation Company (EUAS) Thermal Power Plants Department Annual Reports, 2011 and 2012, EUAS Privatization and Power Plants Pursuance Department Annual Report, 2014. For 2015: Estimation based on an unnamed industry source (undisclosed data). (These estimates differ from our estimation method below by 5% for Yatagan, by 9.5% for Yenikoy and by 13.9% for Kemerkoy.) For 2016-2017: Estimated values using coal consumption design values and nominal generation figures from UCTEA (2017).

rate, and the further retrofits were assumed to be completed by the end of 2024. Each plant was assumed to operate for a total of 50 years. This assumption could well be conservative especially in the case of Yatagan TPP, which is assumed to carry out major retrofits by 2024 and then retire in 2032[3].

CO_2 emissions were calculated based on lignite total carbon content at each plant from Vardar& Yumurtaci (2010) and annual lignite consumption.

During their entire operating life until the end of 2017, the estimated emissions of the plants are 360 million tonnes of CO_2, 9.5 million tonnes of SO_2, 890 kilotonnes of NO_x, 65 kilotonnes of dust and 28,000 kilograms of mercury. For comparison, Turkey's annual CO_2 emissions in 2017 were 410 million tonnes (BP 2018), and estimated mercury emissions in 2010 were 16,000 kilograms per year (AMAP/UNEP 2013).

Figure 2 shows the estimated average stack emissions concentrations from the three plants before and after the installation of the Flue Gas Desulfurization (FGD) units at each plant, as well as under two alternative future scenarios – the emissions levels targeted with the further retrofit investments outlined in the Germany – Turkey Twinning Project and under the latest EU LCP BREF emission limits. Due to the high sulfur content and low calorific value of the lignite, the SO_2 emissions from the plants before the installation of FGDs were massive; their installation around 2008 led to a significant reduction in SO_2 emissions. Mercury emissions and dust emissions decreased slightly as a side benefit. The further retrofits expected to be completed by the end of 2024 would reduce SO_2 and NO_x emissions, but would affect dust emissions only at Yatagan TPP which currently has much poorer dust control performance than the two other plants; mercury emissions would not be affected because there are no target levels indicated. Meeting the latest European standard (LCP BREF) would imply substantial further reductions - emissions of SO_2 and dust would fall by approximately 65% and mercury emissions by 70%.

Figure 2 Estimated average stack emissions concentrations at the Mugla power plants during different periods and future scenarios.

[3] The TPPs have to obtain environmental permits by the end of 2019, in line with the Electricity Market Law (No:6446, 2013, provisional clause 8, amended 2016), but there will be a transition period for emission limits until 2024 when they have to reach EU standards.

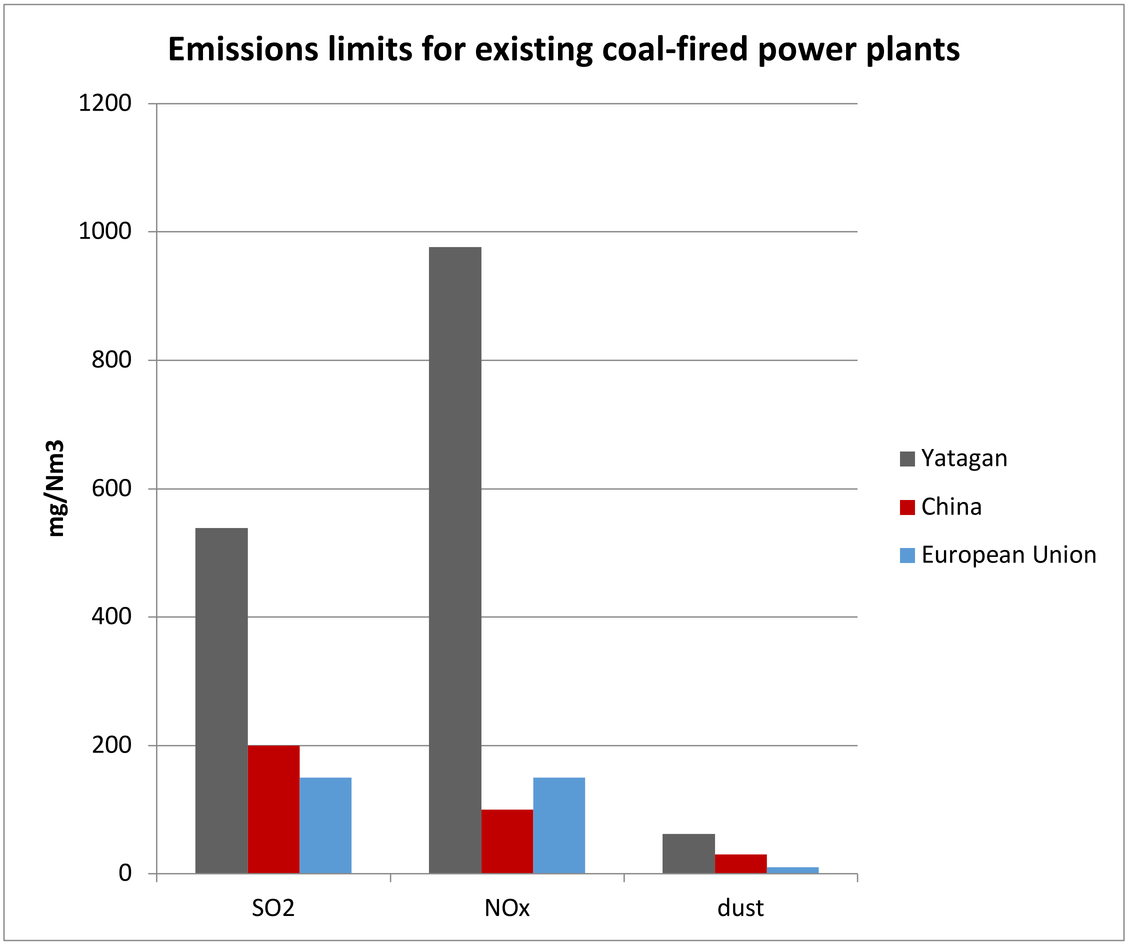

Figure 3 Emission levels of the Yatagan power plant compared with legal limits in China and the European Union, used here as indicators of industry best practice.

Current impacts on air quality

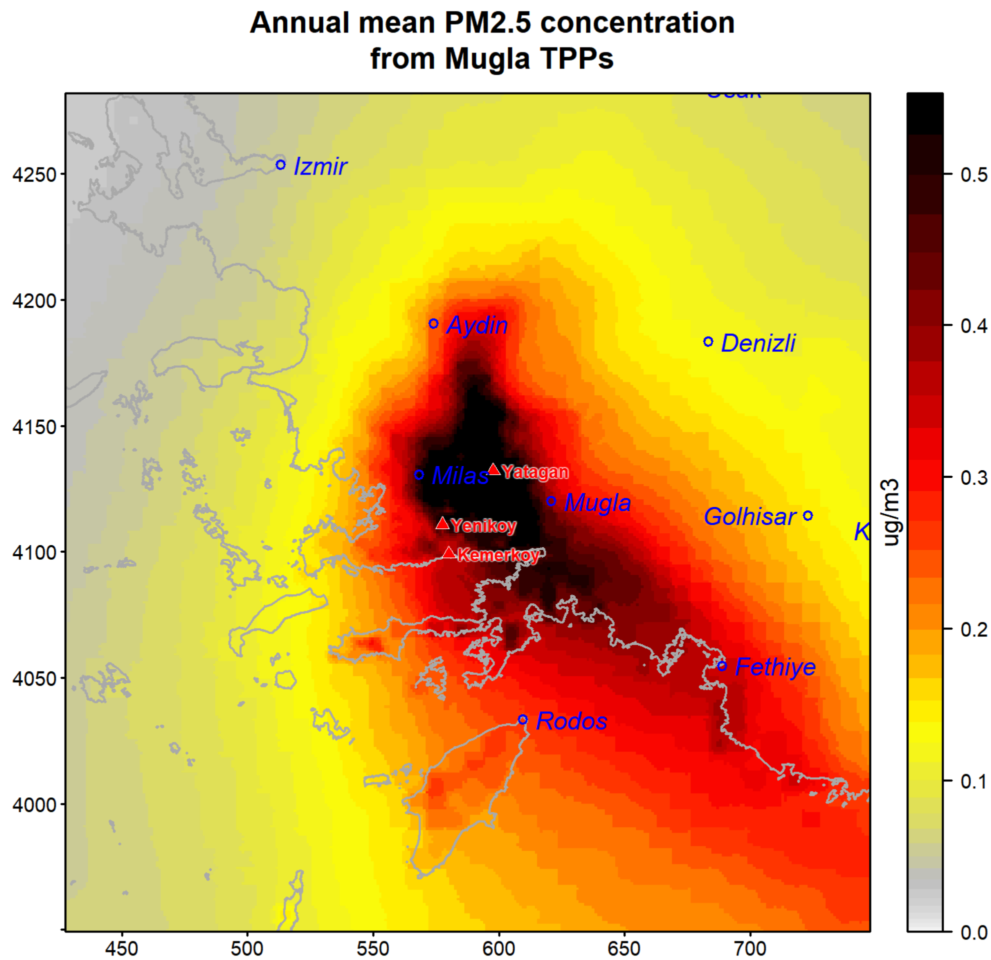

Figure 4 Projected annual average PM2.5 concentration attributable to emissions from the Mugla power plants.

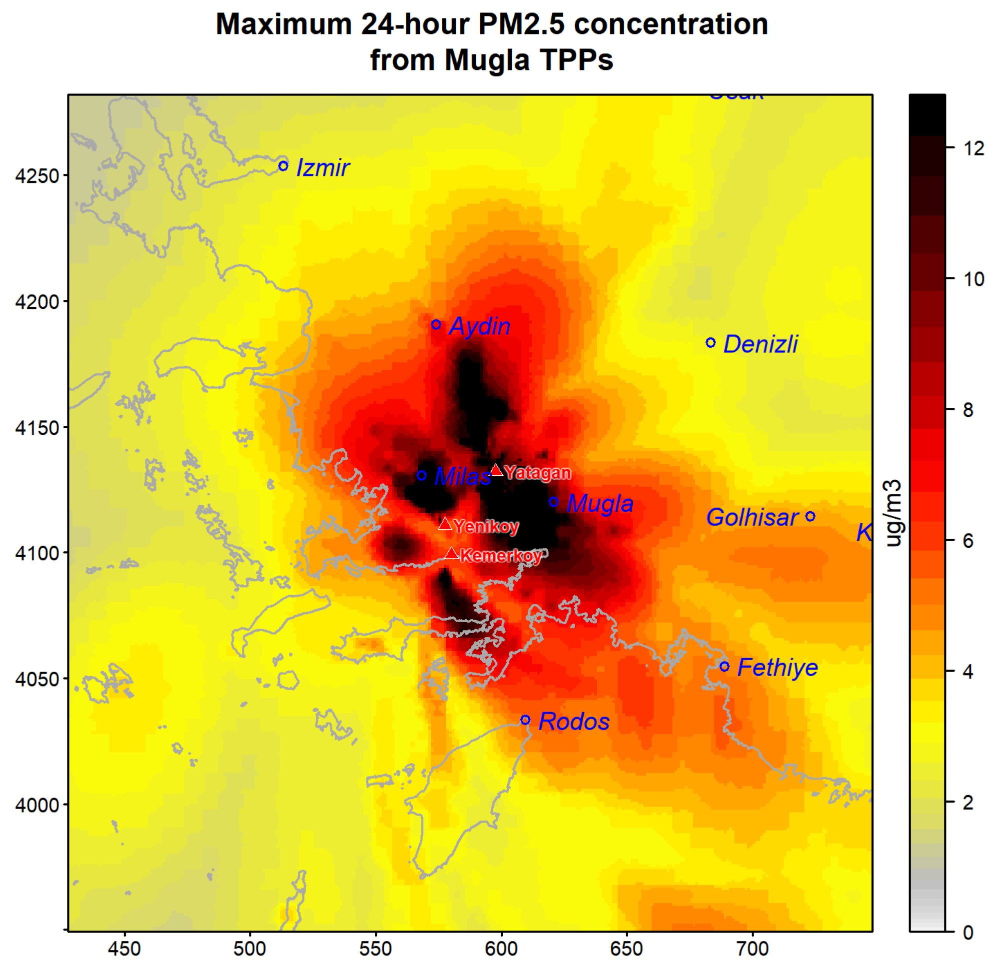

Figure 5 Projected maximum 24 hours PM2.5 concentration attributable to emissions from the Mugla power plants.

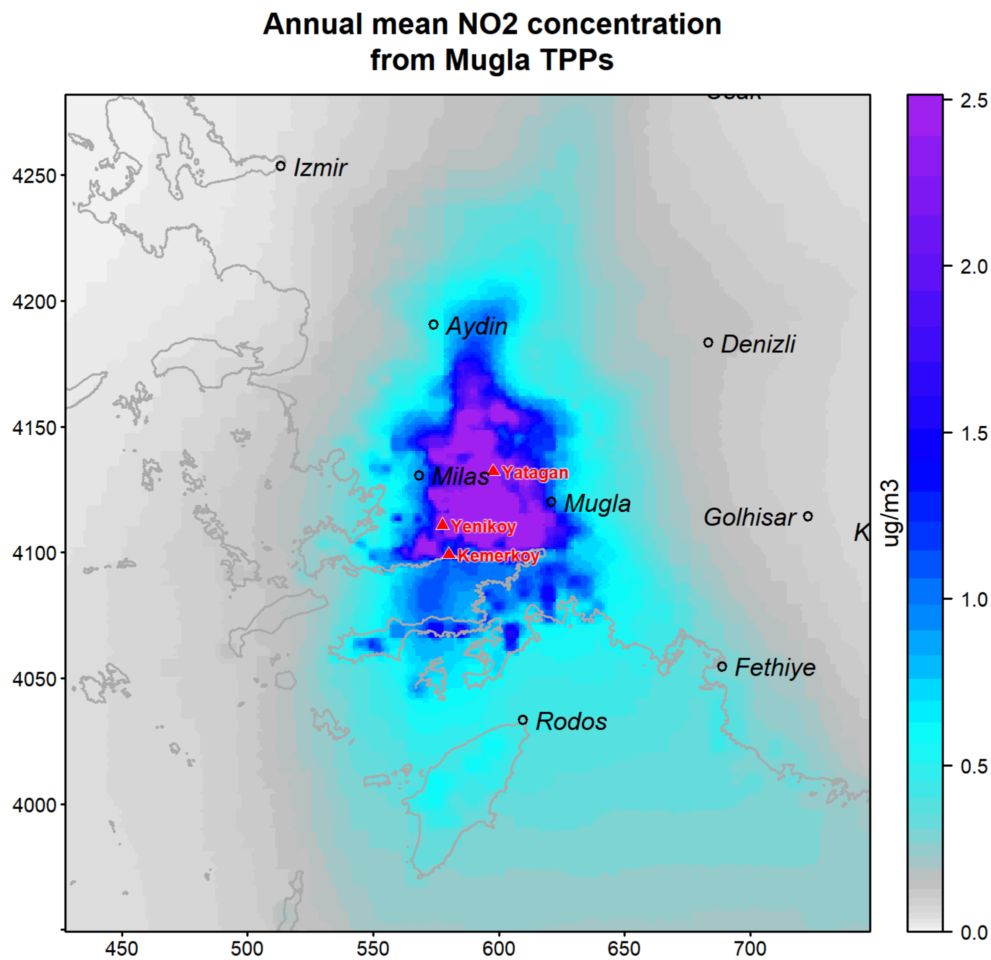

Figure 6 Projected annual average NO2 concentrations caused by emissions from the Mugla power plants.

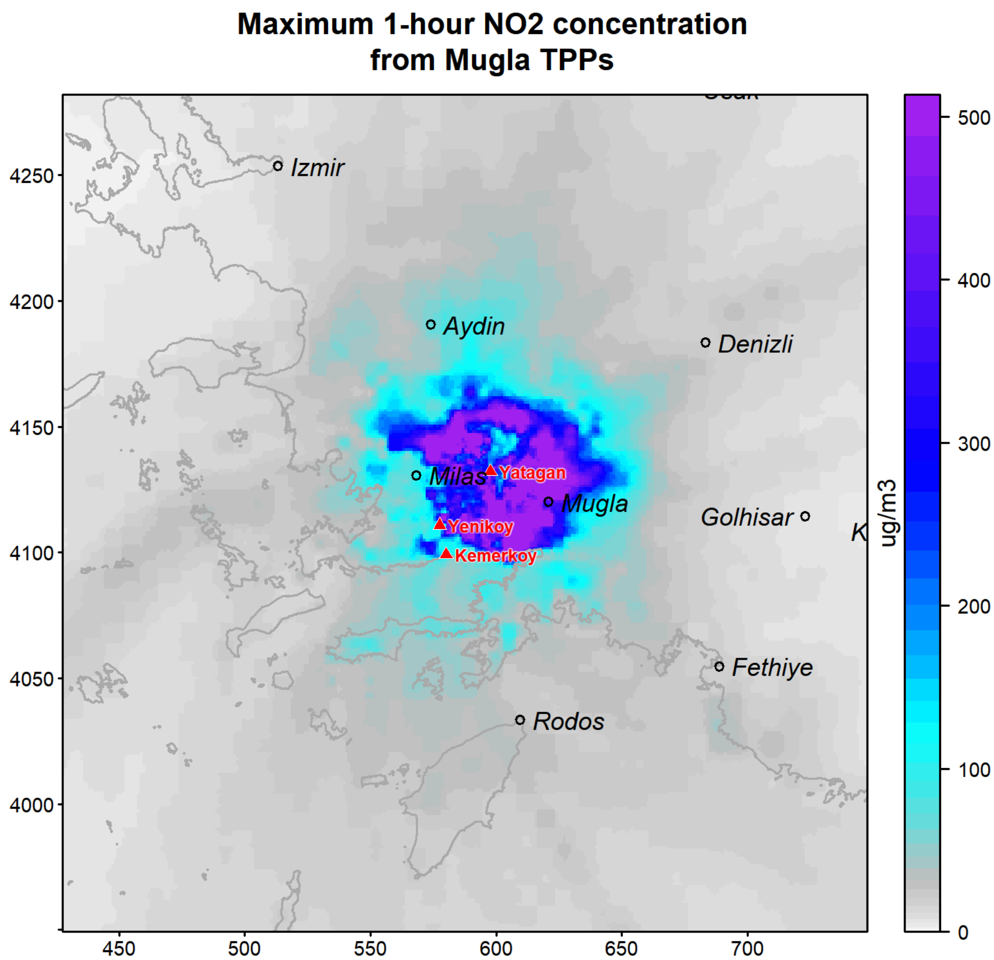

Figure 7 Projected 1-*hour maximum NO2 concentrations caused by emissions from the Mugla power plants.*

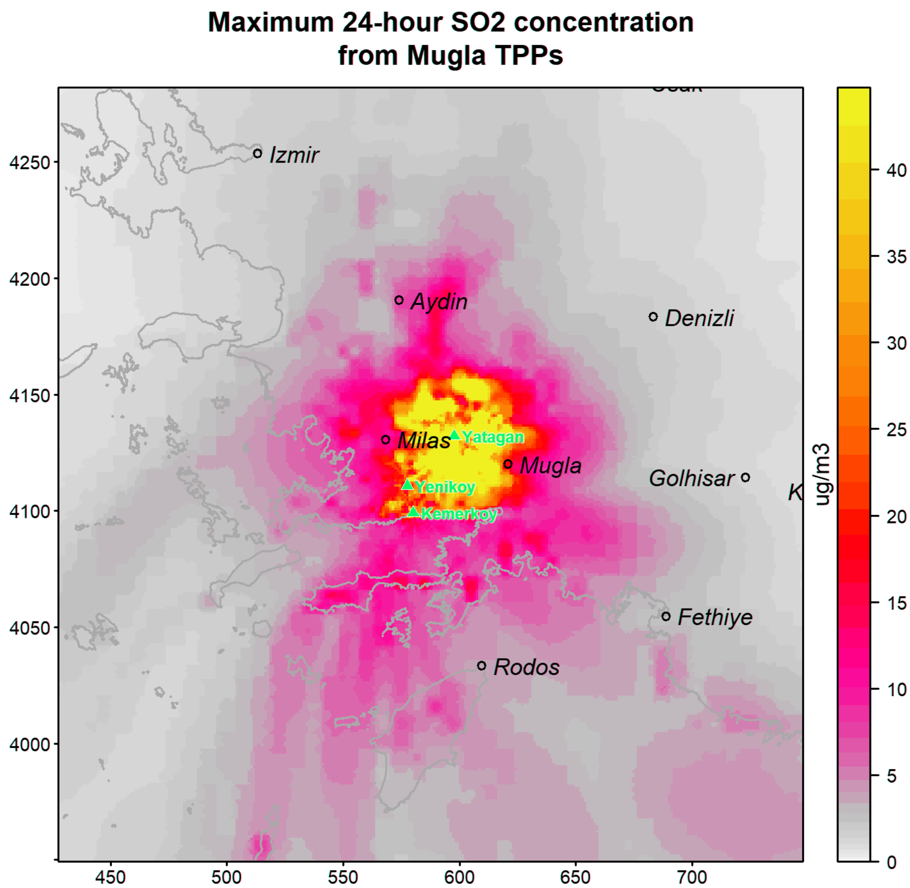

Figure 8 Projected 24-hour maximum SO2 concentrations caused by emissions from the Mugla power plants.

Emissions from the Mugla power plants affect annual PM2.5 pollution levels most significantly over a large area spanning 200 kilometers from Aydin to Milas and along the coast to Fethiye, with the largest impact taking place in Milas (Figures 3 and 4). A significant impact on NO2 levels is seen up to 50km away from the plants (Figure 5). The highest projected NO2 levels occur in Kavaklidere and Ula and highest SO2 levels in Yatagan and Kavaklidere (Figure 8a and 8b). In terms of the contribution to annual average pollution levels of the 3 plants in total, Yatagan is by far the most affected settlement area (Figure 8c).

The emissions from the studied power plants expose an estimated 510,000 people to NO2 concentrations and 80,000 people to SO2 concentrations exceeding WHO guidelines, before considering any other emission sources in the region (Figures 6 and 7). 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.

The power plants were causing exceedances of Turkey's 1-hour air quality limit value for SO2 in at least one location during 1188 hours out of the 8760 hours of the modeled year. The corresponding value for NO2 is 691 hours. Using the slightly lower limit values that apply from the beginning of 2019, the number of hours with exceedances increases to 1377 for SO2 and 751 for NO2.

At the most affected location, the power plants were responsible for an estimated 26 exceedances of the Turkish 1-hour limit value for SO2 concentration and 18 exceedances of the 1-hour limit value for NO2 concentration during the modeled year. The highest 1-hour concentrations are 10 times as high as the limit values (

Table *1*). The predicted peak concentrations for SO2 carry a very high risk of severe acute health effects – they exceed U.S. EPA level 2 Acute Exposure Guideline Level (AEGL-2), a level “above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, longlasting adverse health effects or an impaired ability to escape” (National Research Council 2010).

Table 1 Projected air quality impacts at most affected locations, with plants at full operation.

CALPUFF - TOTAL EMISSIONS CONTRIBUTION TO AIR POLLUTION																					
Parameter	Modeling output **1 HR**	TR Industrial Emissions Regulation Hourly Limit Value 2018	TR Industrial Emissions Regulation Hourly Limit Value 2019-2023	TR Industrial Emissions Regulation Hourly Limit Value 2024 and beyond	EU	**WHO**	Modeling output **24 HR** (short term limit value)	TR Industrial Emissions Regulation Daily Limit Value (short term limit value) 2018	TR Industrial Emissions Regulation Daily Limit Value (short term limit value) 2019-2023	TR Industrial Emissions Regulation Daily Limit Value (short term limit value) 2024 and beyond	EU	**WHO**	Modeling output **ANNUAL** (long term limit value)	TR Industrial Emissions Regulation Annual Limit Value (long term limit value) 2018	TR Industrial Emissions Regulation Annual Limit Value (long term limit value) 2019-2023	TR Industrial Emissions Regulation Annual Limit Value (long term limit value) 2024 and beyond	EU Directive	**WHO**	Modeling output **ANNUAL DEPOSITION**
SO_2 (µg/m^3)	**4347,852** -	380 (not to exceed 24 times a year)	350 (not to exceed 24 times a year)	350 (not to exceed 24 times a year)	**350 µg/m^3**	-	**387,8011**	**150**	**125**	**125**	125 µg/m^3	20 µg/m^3	**8,6703**	20	20	20	-	-	**437,9720 kg/ha/yr SO2 equivalent**
NO_2 (µg/m^3) -	**4305,853** -	260 (not to exceed 18 times a year)	250 (not to exceed 18 times a year)	200 (not to exceed 18 times a year)	**200 µg/m^3**	**200 µg/m^3**	**314,3104**	**-**	**-**	**-**	-	-	**5,0160**	44	40	40	40 µg/m^3	40 µg/m^3	
PM_{10} (µg/m^3)	**325,8364**	-	-	-	**-**	-	**30,78613**	**60** (not to exceed 35 times a year)	**50** (not to exceed 35 times a year)	**50** (not to exceed 35 times a year)	50 µg/m^3	50 µg/m^3	**1,2517**	44	40	40	40 µg/m^3	20 µg/m^3	**29,8365 kg/ha/yr**
$PM_{2.5}$ (µg/m^3)	**201,8042**	-	-	-	**-**	-	**23,62479**	**-**	**-**	**-**	**-**	25 µg/m^3	**0,9444**	-	-	-	20 µg/m^3	10 µg/m^3	-
tsp (µg/m^3)	**355,5621**	-	-	-	**-**	-	**37,14735**	-	-	-	**-**	-	**1,3741**	-	-	-	**-**	-	

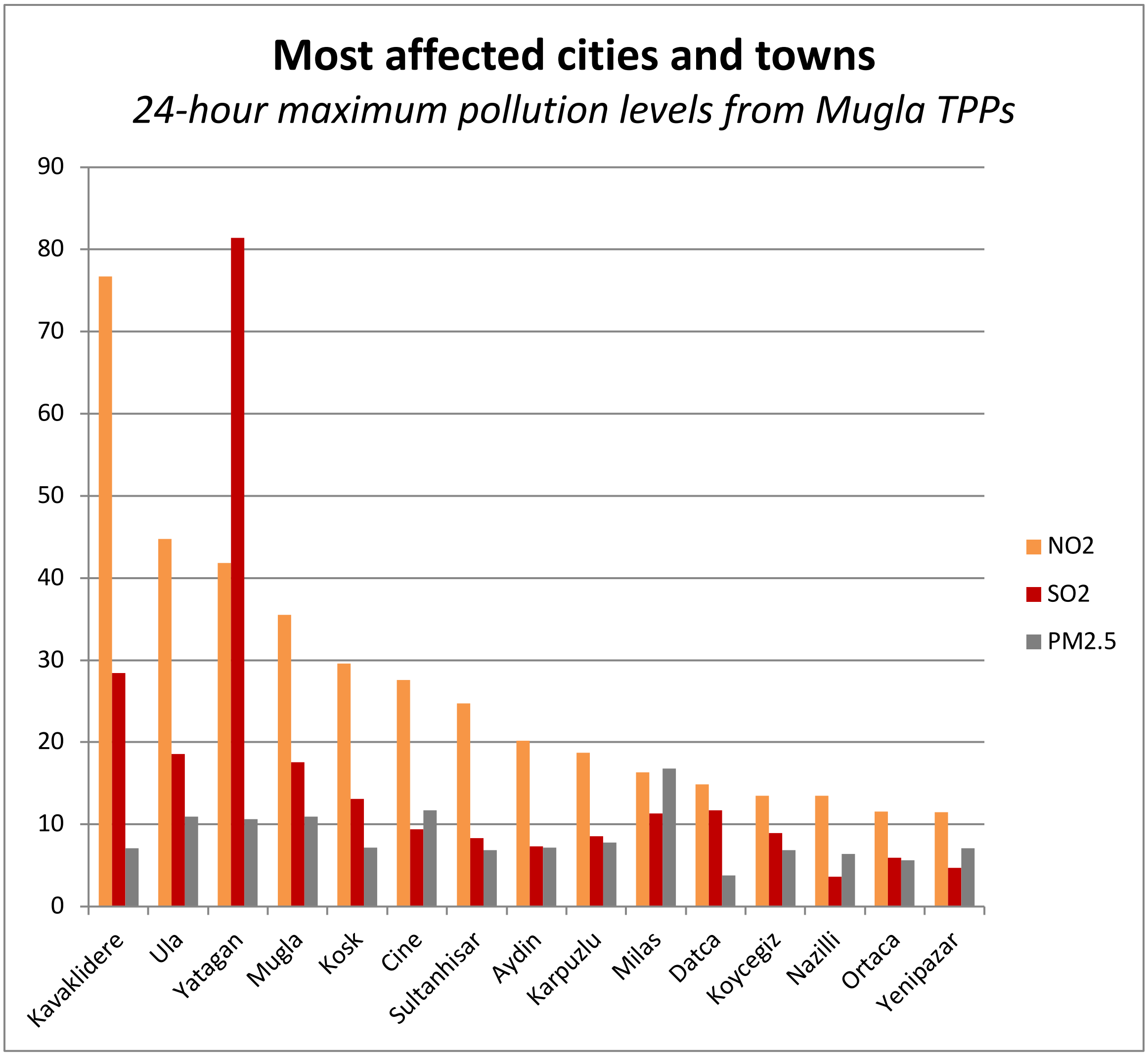

Figure 8a Most affected towns on the basis of 24-hour maximum concentrations.

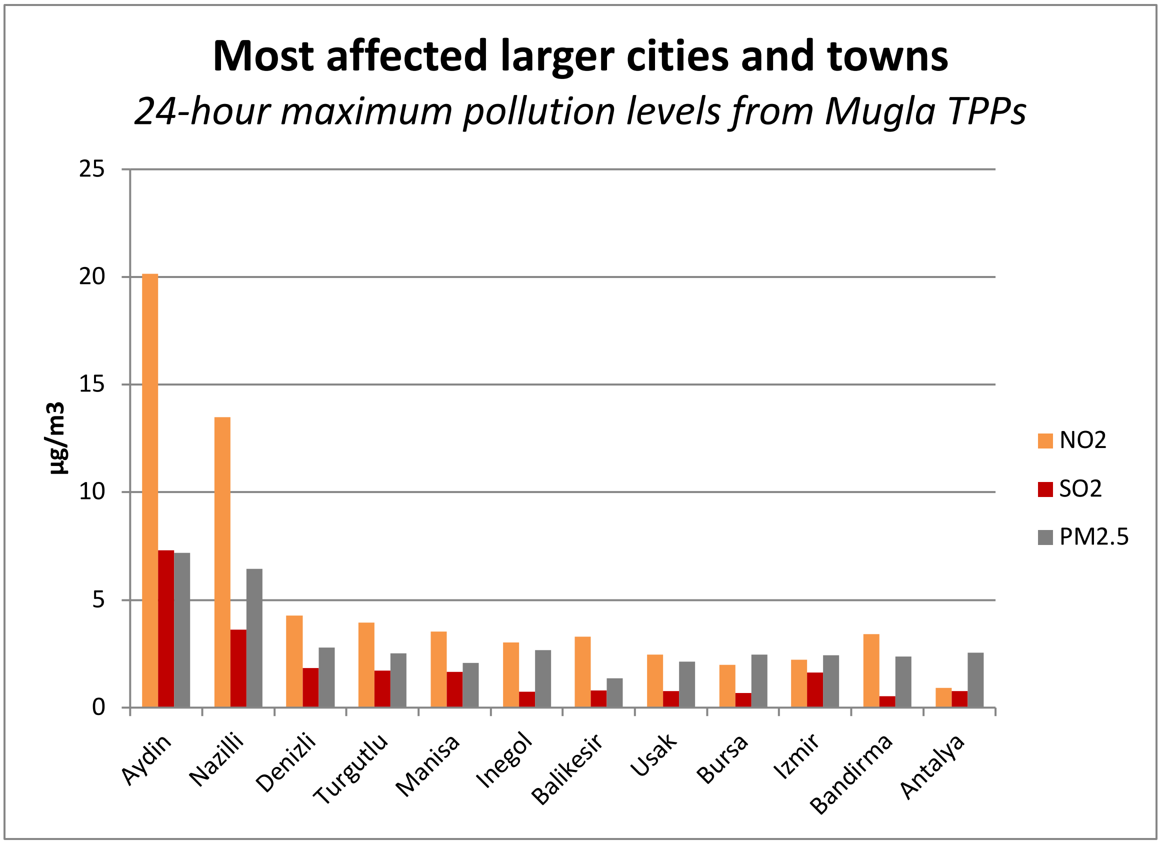

Figure 8b Most affected larger cities and towns (over 100,000 people) on the basis of 24-hour maximum concentrations.

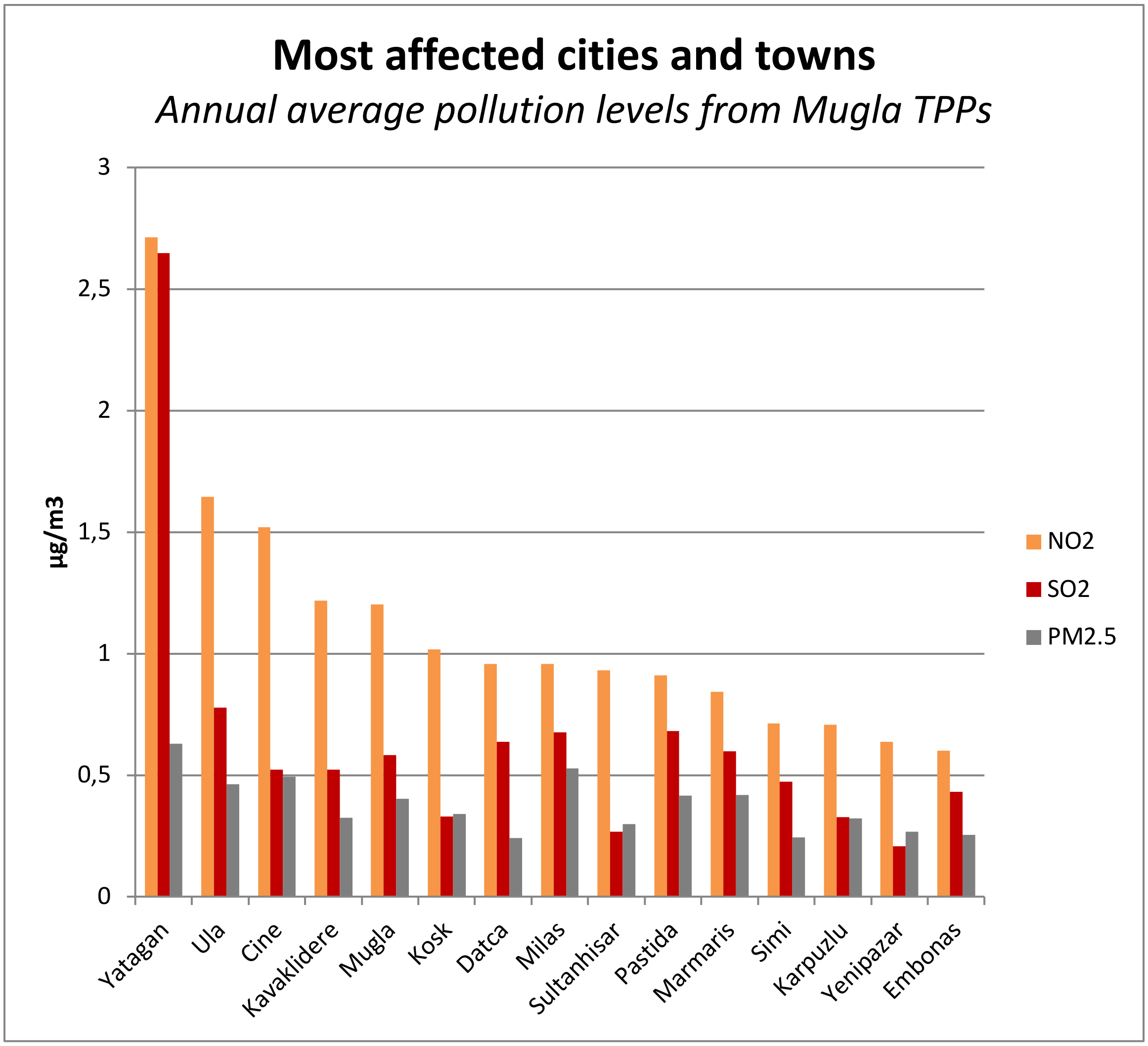

Figure 8c Most affected towns on the basis of annual average concentrations.

Toxic fallout

The pollution emissions from coal-fired power plants lead to deposition of toxic heavy metals, fly ash, acid rain and mercury. The deposition mainly occurs during rains and is consequently largest in the vicinity of the power plants and on the slopes of surrounding hills and mountains.

Of the estimated 1,100kg/year of mercury emitted by the plants, approximately 610kg or 55% is deposited within the modeling domain. Of this, 220kg is deposited into the Mediterranean, 150kg onto forested land and 120kg to cropland. Mercury deposition rates as low as 125mg/ha/year can lead to accumulation of unsafe levels of mercury in fish (Swain et al 1992). The plants are estimated to cause mercury deposition above 125mg/ha/yr over a large area approximately 130km across, with a population of 80,000 people (Figure 9).

Mercury deposition into the Mediterranean is a particular concern.

Acid deposition from the plants affects forests and other natural ecosystems. Farmers can see affected yields or increased input costs as they have to neutralize the deposition. Acid rain also damages property and culturally important buildings. Coal fly ash contains toxic heavy metals that are associated with a range of health risks. Most intense acid and fly ash deposition especially the mountainous, forested area between Mugla, Yatagan and the coast, with deposition in the most affected areas exceeding 50kg of SO2-equivalent per hectare per year in an area of approximately 90km^2. Fly ash deposition rates exceeding 5kg/ha/year are predicted in the immediate vicinity of the plant in an area of approximately 20km^2. An estimated 35% of the acid deposition and 40% of fly ash deposition takes place onto forested land, with 35% of acid deposition and 30% of fly ash deposition affecting cropland.

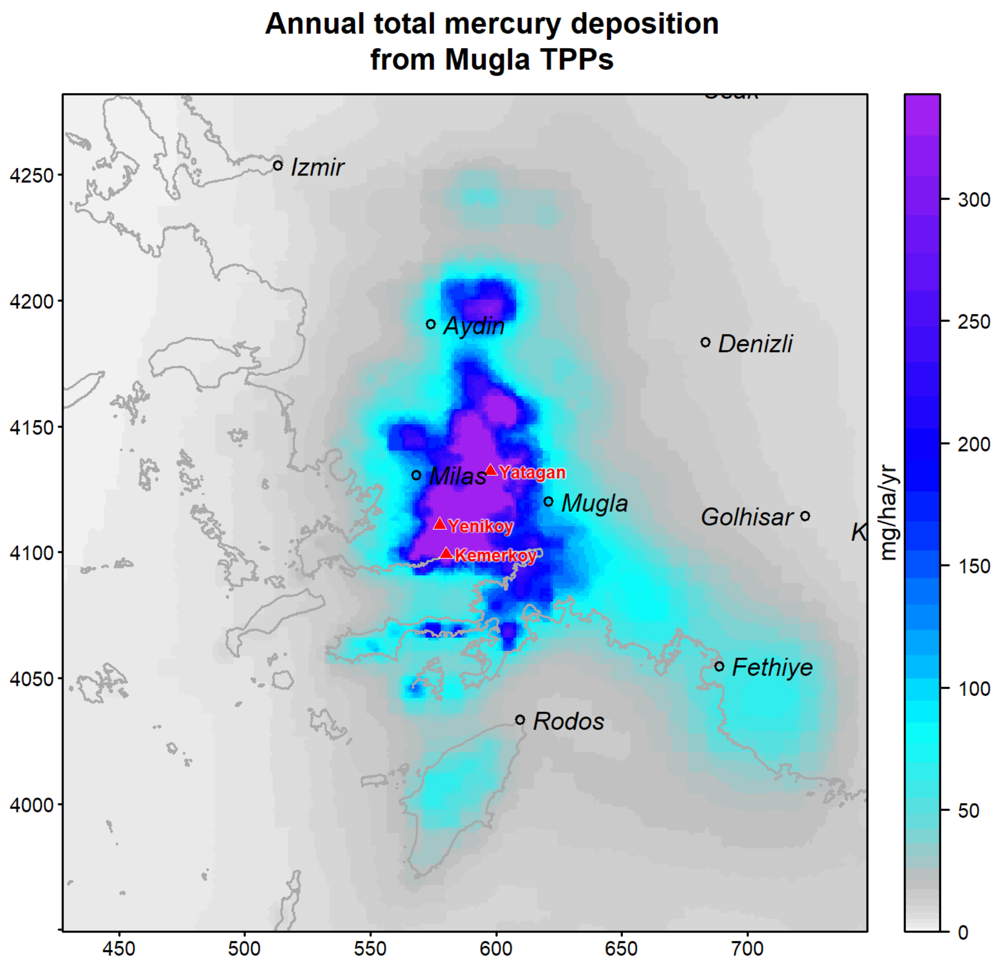

Figure 9 Projected mercury deposition from the Mugla power plants.

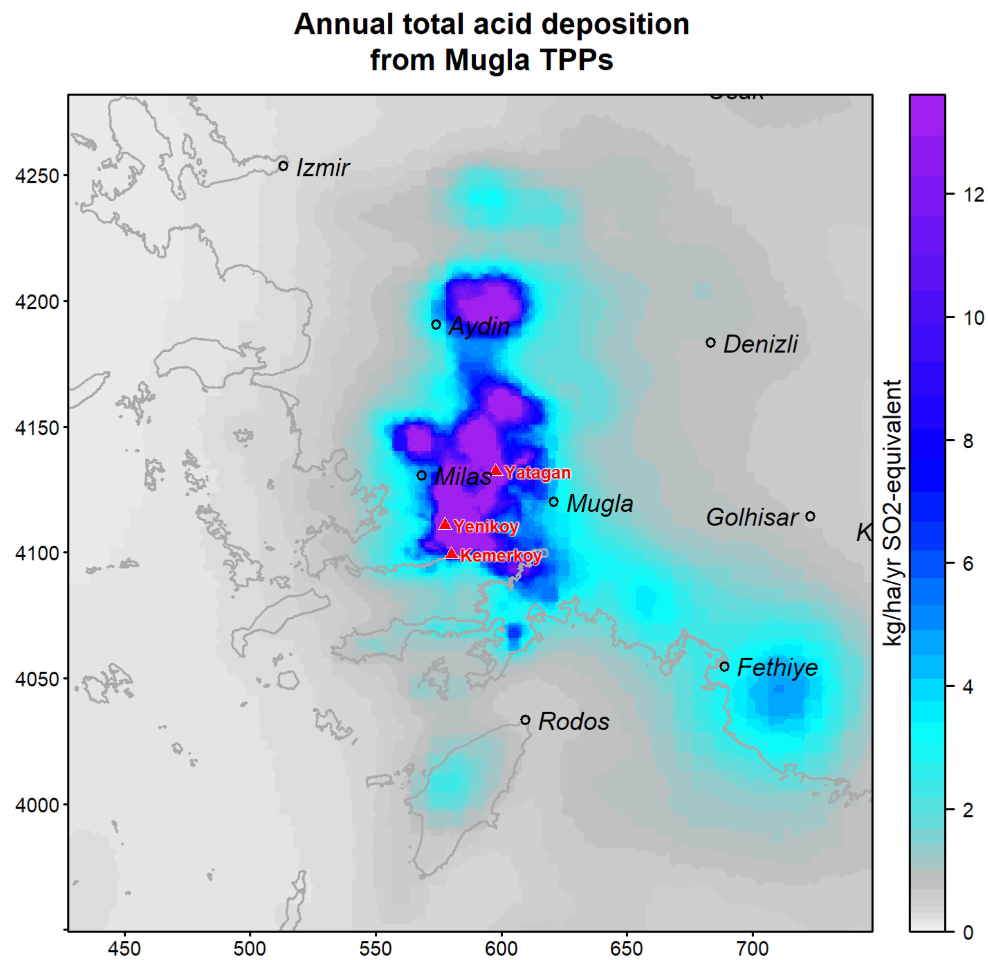

Figure 10 Projected acid deposition from the Mugla power plants.

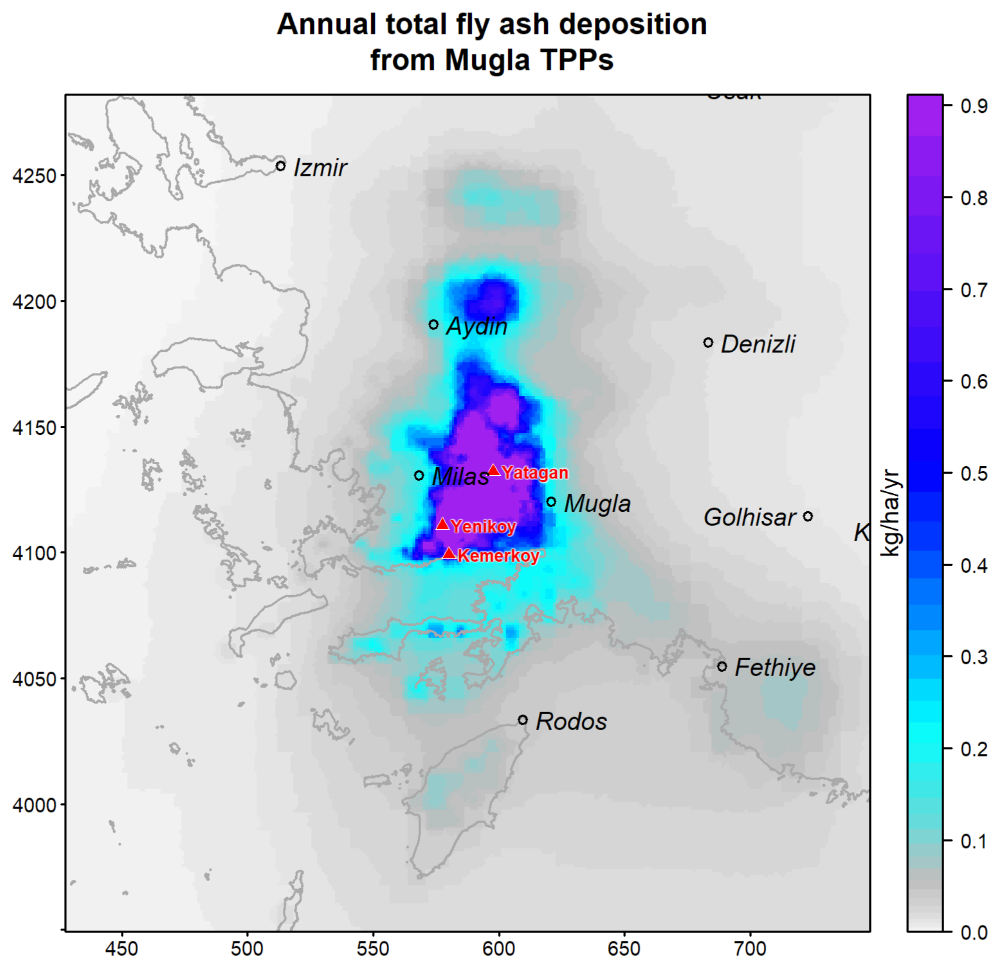

Figure 11 Projected fly ash deposition from the Mugla power plants.

Health impacts

The emissions from the currently operating coal-fired units in Mugla are likely to result in approximately 280 premature deaths and 100 low birth weight births per year due to exposure to PM2.5 and NO2 (Table 5). Other impacts include 140 new cases per year of chronic bronchitis in adults, 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.

Effect	Pollutant	Value	95% confidence interval	Unit
premature deaths	NO2	56	*(32 - 81)*	cases per year
premature deaths	PM2.5	224	*(146 - 297)*	cases per year
TOTAL premature deaths		280		
low birth weight	PM2.5	96	*(30 - 166)*	births per year
asthmatic and bronchitic symptoms in children	PM10	18	*(4 - 33)*	cases per day
chronic bronchitis in adults	PM10	135	*(48 - 211)*	new cases per year
bronchitis in children	PM10	730	*(-192 - 1650)*	cases
hospital admissions	NO2	89	*(57 - 120)*	cases per year
hospital admissions	PM2.5	223	*(9 - 436)*	cases per year
TOTAL hospital admissions		312		
sickness days	PM2.5	1260	*(1120 - 1410)*	cases per day
lost working days	PM2.5	61300	*(143 - 192)*	days per year

Table 2 Estimated premature deaths and other health impacts caused by emissions from the studied power plants.

Transboundary impacts

Approximately 53% of the PM2.5 exposure and 25% of the NO2 exposure to populations attributed to the power plants takes place outside of Turkey, with the largest transboundary impact taking place in Egypt, followed by Israel, Greece and Palestine. Health impacts in Egypt are significant due to the large exposed population and due to prevailing wind directions.

The largest air quality impacts outside of Turkey take place on Rhodes and other Dodecanese islands. During unfavorable weather conditions, the increase in daily average SO2 levels caused by the emissions from the plants reaches 11µg/m3, more than half of the WHO guideline, while increases in hourly NO2 level and daily PM2.5 reach 50µg/m3 and 6µg/m3, one quarter of the WHO guideline. This means that the plants are likely to contribute to violations of air quality standards on Rhodes when other emission sources are taken into account.

Cumulative impacts

During the entire period from commissioning of the first plant (Yatagan) in 1983 to the end of 2017, the three power plants have been responsible for an estimated 45,000 premature deaths. A further 5,300 premature deaths are projected to occur if each plant continues to operate until it reaches a 50 year operating life, even if all planned/announced retrofit projects to improve the plants' environmental performances are realized and national legal emission limits are met. Out of these deaths, approximately 1,300 would be avoided if the plants met the latest EU Large Combustion Plants Best Available Technology Reference emission values, which are legally binding in the EU, by 2024.

Table 3 Estimated cumulative health impacts caused by the studied power plants to date (1983-2017).

Effect	Pollutant	Unit	Central

premature deaths	total	cases	45,300	(29,400-60,200)
premature deaths	NO2	Cases	1,380	(790-2,970)
premature deaths	PM2.5	Cases	43,900	(28,600-58,200)
low birth weight	PM2.5	cases	18,700	(5,790-32,400)
asthmatic and bronchitic symptoms in children	PM10	million cases	1.31	(0.28-2.37)
chronic bronchitis in adults	PM10	new cases	26,400	(9,360-41,300)
bronchitis in children	PM10	cases	142,000	(-37,400-322,000)
hospital admissions	NO2	cases	2,300	(1,480-3,120)
hospital admissions	PM2.5	cases	43,600	(1,780-85,500)
sickness days	PM2.5	cases	246,000	(220,000-277,000)
lost working days	PM2.5	million days	12.0	(10.2-13.8)

Table 4 Projected cumulative future health impacts caused by the studied power plants over their remaining operating life (2018-2043).

Effect	Pollutant	Unit	Central	95% confidence interval
premature deaths	total	cases	5,270	(3,370-7,080)
premature deaths	NO2	cases	840	(480-1,810)
premature deaths	PM2.5	cases	4,430	(2,890-5,880)
low birth weight	PM2.5	cases	1,880	(584-3,270)
asthmatic and bronchitic symptoms in children	PM10	cases	130,000	(28,000-235,000)
chronic bronchitis in adults	PM10	new cases	2,660	(943-4,160)
bronchitis in children	PM10	cases	14,100	(-3,700-31,900)
hospital admissions	NO2	cases	1,290	(825-1,750)
hospital admissions	PM2.5	cases	4,350	(178-8,530)
sickness days	PM2.5	cases	24,600	(22,000-27,600)
lost working days	PM2.5	million days	1.23	(1.04-1.41)

References

AMAP/UNEP, 2013. Technical Background Report for the Global Mercury Assessment 2013. Arctic Monitoring and Assessment Programme, Oslo, Norway/UNEP Chemicals Branch, Geneva, Switzerland.

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/

BP 2018. Statistical Review of World Energy 2018. http://www.bp.com/statisticalreview

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

European Space Agency (ESA), 2018. Land Cover Maps – v2.0.7. http://maps.elie.ucl.ac.be/CCI/viewer/download.php

German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [BMU] 2006: Large combustion plants according to LCP-Directive in Turkey. Twinning-Project TR-03-EN-01. Ministry of Environment and Urbanization, Directorate General of Environmental Impact Assessment, Permit and Inspection. Official Correspondence No. E.17872 dated Nov 26, 2017 and No. E.20695 dated Dec 30, 2017.

Güven, S. et al. (2007). Termik Santrallerde AB Büyük Yakma Direktifi’ne Uyum, TEPAV Nisan 2008 Raporu. [Pilot Impact Analysis Study - Adaptation of Thermal Plants to the EU Directive on Large Combustion Plants.] The Economic Policy Research Foundation of Turkey, Ankara.

Huscher, Myllyvirta, Gierens 2017. Modellbasiertes Health Impact Assessment zu grenzüberschreitenden Auswirkungen von Luftschadstoffemissionen europäischer Kohlekraftwerke. Umweltmedizin - Hygiene - Arbeitsmedizin Band 22, Nr. 2 (2017) https://www.ecomed-umweltmedizin.de/leseproben/self/umweltmedizin--hygiene--arbeitsmedizin-band-22-nr-2-2017-.pdf

Mills et al 2016. Distinguishing the associations between daily mortality and hospital admissions and nitrogen dioxide from those of particulate matter: a systematic review and meta-analysis. BMJ Open 6:e010751. http://dx.doi.org/10.1136/bmjopen-2015-010751

Ministry of Environment and Urbanization, Directorate General of Environmental Impact Assessment, Permit and Inspection. Official Correspondence No. E.17872 dated Nov 26, 2017 and No. E.20695 dated Dec 30, 2017.

National Research Council 2010. Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8. Washington, DC: The National Academies Press. https://doi.org/10.17226/12770

Swain EB et al, 1992. Increasing Rates of Atmospheric Mercury Deposition in Midcontinental North America. Science 257:784-787.

UCTEA Chamber of Mining Engineers Energy Working Group [TMMOB Maden Mühendisleri Odası] 2015. Enerji ve Kömür Raporu, Ankara, p: 85. www.maden.org.tr/resimler/ekler/22ed738b2c7ba36_ek.pdf

UCTEA Chamber of Mechanical Engineers [TMMOB Makine Mühendisleri Odası, MMO] 2017: Thermal Power Plants 2017 Report.

United Nations, Department of Economic and Social Affairs, Population Division [UN DESA] 2017. World Population Prospects: The 2017 Revision. https://esa.un.org/unpd/wpp/Download/Standard/Population/

UNEP, 2017. Toolkit for Identification and Quantification of Mercury Releases. UN Environment Chemicals Branch, Geneva, Switzerland.

Vardar N & Yumurtaci Z 2010. Emissions estimation for lignite-fired power plants in Turkey. Energy Policy 38:243–252.

World Bank undated. World Development Indicators. http://databank.worldbank.org/data/home.aspx

World Health Organization (WHO) 2013. Health risks of air pollution in Europe-HRAPIE project. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide. http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf?ua=1

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

Appendix 1: Emission source data

Table 5. Modeled sources and their locations.

Source	Source Description	Coordinates (UTM 35N, meters)	
		X	Y
Yatagan 1	Unit 1 Flue gas stack	597713.4	4132197.8
Yatagan 2	Unit 2 Flue gas stack	597647.7	4132162.0
Yatagan 3	Unit 3 Flue gas stack	597618.5	4132134.6
Yenikoy 1	Flue gas stack of Unit 1 and Unit 2	577405.0	4110790.0
Yenikoy 2	Auxiliary boiler stack	577546.8	4110715.3
Yenikoy 3	stack of the limestone feeding bunker-1	577369.3	4110723.2
Yenikoy 4	stack of emergency limestone feeding bunker	577382.9	4110718.4
Yenikoy 5	stack of limestone stockyard conveyor belt	577425.0	4110674.4
Yenikoy 6	stack of the limestone feeding bunker-2	577377.9	4110707.3
Yenikoy 7	Venting stack of ash hopper	577486.5	4110648.5
Yenikoy 8	Venting stack of ash hopper	577485.3	4110644.5
Yenikoy 9	Venting stack of ash hopper	577480.4	4110637.6
Yenikoy 10	Venting stack of ash hopper	577480.9	4110637.3
Kemerkoy 1	Unit 1 Flue gas stack	580095.0	4099181.0
Kemerkoy 2	Unit 2 Flue gas stack	580089.0	4099181.0
Kemerkoy 3	Unit 3 Flue gas stack	580095.0	4099175.0
Kemerkoy 4	Auxiliary boiler stack	580267.0	4099221.0
Kemerkoy 5	Venting stack of ash hopper	580049.0	4099534.0
Kemerkoy 6	Venting stack of ash hopper	580049.0	4099534.0
Kemerkoy 7	Venting stack of ash hopper	580052.8	4099551.1
Kemerkoy 8	Venting stack of ash hopper	580052.8	4099551.1
Kemerkoy 9	Venting stack of ash hopper	580053.1	4099569.0
Kemerkoy 10	Venting stack of ash hopper	580053.1	4099569.0
Kemerkoy 11	Limestone dust collector-1	580051.2	4098932.9
Kemerkoy 12	Limestone dust collector-2	580027.8	4098952.0
Kemerkoy 13	Limestone dust collector-3	580045.4	4098944.8
Kemerkoy 14	Limestone dust collector-4	580040.5	4099051.7
Kemerkoy 15	Limestone dust collector-5	580033.8	4099049.2
Kemerkoy 16	Limestone dust collector-6	580021.9	4099103.3

Table 6. Stack and flue gas characteristics of the modeled sources.

Source	stack height, m	base elevation, msl	diameter, m	exit velocity, m/s	exit temperature, K
Yatagan 1	120.0	338.1	6.4	12.9	364.2
Yatagan 2	120.0	339.4	6.4	12.9	364.2
Yatagan 3	120.0	341.2	6.4	12.9	364.2
Yenikoy 1	200.0	285.4	10.8	10.9	372.4
Yenikoy 2	16.2	286.0	0.8	6.6	479.9
Yenikoy 3	38.0	285.3	0.6	16.9	295.0
Yenikoy 4	9.0	285.4	0.6	17.6	300.3
Yenikoy 5	19.5	285.8	0.6	12.1	297.5
Yenikoy 6	38.0	285.5	0.6	17.3	295.0
Yenikoy 7	46.5	286.6	0.5	7.4	298.8
Yenikoy 8	46.5	286.8	0.5	7.2	301.4
Yenikoy 9	46.5	287.1	0.5	8.6	294.6
Yenikoy 10	46.5	287.2	0.5	8.5	294.0
Kemerkoy 1	320.0	15.8	5.0	22.6	363.4
Kemerkoy 2	320.0	15.8	5.0	17.4	373.0
Kemerkoy 3	320.0	14.8	5.0	19.2	352.6
Kemerkoy 4	12.5	25.7	0.9	7.6	436.9
Kemerkoy 5	46.5	31.6	0.5	9.5	294.9
Kemerkoy 6	46.5	31.6	0.5	9.6	294.7
Kemerkoy 7	46.5	34.5	0.5	8.2	297.3
Kemerkoy 8	46.5	34.5	0.5	8.7	296.4
Kemerkoy 9	46.5	37.6	0.5	9.2	293.9
Kemerkoy 10	46.5	37.6	0.5	9.4	296.5
Kemerkoy 11	25.5	6.7	0.5	9.4	302.5
Kemerkoy 12	6.0	7.0	0.4	8.3	300.0
Kemerkoy 13	6.0	7.0	0.4	7.2	298.3
Kemerkoy 14	6.0	7.1	0.4	7.7	297.3
Kemerkoy 15	6.0	7.1	0.4	8.0	298.5
Kemerkoy 16	14.5	7.7	0.4	6.2	298.6

Table 7. Emission rates and operating rates of the modeled sources (operating rate of zero denotes an "intermittent" source that was excluded from annual average air quality impacts).

Source	Emission rate at full operation (g/s)			Operating rate
	SO2	NOx	dust	
Yatagan 1	157.1	284.8	18.2	0.534
Yatagan 2	157.1	284.8	18.2	0.534
Yatagan 3	157.1	284.8	18.2	0.534
Yenikoy 1	362.1	265.1	11.6	0.735
Yenikoy 2	0.482	0.150	0.014	0.000
Yenikoy 3	0.000	0.000	0.021	0.000
Yenikoy 4	0.000	0.000	0.010	0.000
Yenikoy 5	0.000	0.000	0.026	0.000
Yenikoy 6	0.000	0.000	0.014	0.000
Yenikoy 7	0.000	0.000	0.018	0.000
Yenikoy 8	0.000	0.000	0.021	0.000
Yenikoy 9	0.000	0.000	0.021	0.000
Yenikoy 10	0.000	0.000	0.024	0.000
Kemerkoy 1	167.7	134.7	5.4	0.551
Kemerkoy 2	192.0	102.1	4.9	0.551
Kemerkoy 3	114.4	137.0	5.5	0.551
Kemerkoy 4	0.826	0.250	0.024	0.000
Kemerkoy 5	0.000	0.000	0.024	0.000
Kemerkoy 6	0.000	0.000	0.026	0.000
Kemerkoy 7	0.000	0.000	0.021	0.000
Kemerkoy 8	0.000	0.000	0.025	0.000
Kemerkoy 9	0.000	0.000	0.025	0.000
Kemerkoy 10	0.000	0.000	0.025	0.000
Kemerkoy 11	0.000	0.000	0.025	0.000
Kemerkoy 12	0.000	0.000	0.016	0.000
Kemerkoy 13	0.000	0.000	0.018	0.000
Kemerkoy 14	0.000	0.000	0.018	0.000
Kemerkoy 15	0.000	0.000	0.019	0.000
Kemerkoy 16	0.000	0.000	0.019	0.000

Table 8. Assumed size distribution of primary particles, based on U.S. EPA AP-42 for combustion sources (coal-fired power plant with electrostatic precipitators) and on EMEP Emission Inventory Guidelines for coal handling for fugitive dust.

	Aerodynamic diameter, microns		
Source type	>10	2.5 - 10	<2.5
combustion	0.325	0.375	0.300
fugitive dust	0.528	0.416	0.056

Appendix 2: 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.

Meteorological data for the simulations was obtained from four surface meteorological stations, Mugla, Milas, Bodrum and Yatagan, and one upper air sounding station in the area. Additional 3-dimensional meteorological data 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, 7.5km and 2.5km horizontal resolutions and 12 vertical levels was used, centered on the power plant.

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.

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 2010 from NASA**

SEDAC[4], 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 Turkey and neighboring countries were obtained from WHO Global Health Estimates (2014), birth rates and incidence of low birth weight from World Bank (undated).

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.

For the cumulative historical and future impacts, the effect of population growth was taken into account. Grid-level population in each country was scaled up or down to match the total population during each year using data from UN World Population Prospects 2017 (UN DESA 2017). Internal migration and epidemiological change was not taken into account due to the complexity of implementing the projections in the health impact assessment framework – doing so would increase future impacts and reduce past impacts.

Deposition results were differentiated by land use type using the European Space Agency global land use map for the year 2015 at 300m resolution (ESA 2018; see Figure 12 Land use map used for assessing deposition impacts (ESA 2018).). Land use codes 10-30 were mapped as cropland; codes 50-100 and 160-170 were mapped as forest.

Table 4 Risk ratios used for health impact assessment.

Effect	Pollutant	Central	Low	High
postneonatal mortality	PM10	1.04	1.02	1.07
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

[4] http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-count-future-estimates

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[5]	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 12 Land use map used for assessing deposition impacts (ESA 2018).

[5] In the results, the central and low values are adjusted down by 1/3 to remove potential overlap with PM2.5-related deaths as indicated by WHO (2013).