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Centre for Research on Energy and Clean Air

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Key findings

- We calculated the air quality impacts from Bulgaria's coal-fired power plants (CFPPs) cumulated over 2023–2038 under three scenarios of different phase-out pathways.
- In the first scenario (Scenario 1), phase out is delayed until 2038 and all Bulgarian CFPPs maintain current power capacities throughout the time period.
- Under Scenario 1, air pollution from Bulgarian CFPPs will have a devastating impact on public health and the economy, including 5,500 (3,400–9,100) premature deaths; 4,600 (440–8,700) hospital admissions; 132,000 (29,000–237,000) cases of asthma symptoms in children; 13,600 (-3,600–30,800) cases of bronchitis in children; 2,700 (950–4,200) cases of bronchitis in adults; 1,150 (360–2,000) low birth weights; 2,100 (1,000–2,300) preterm births; 12 (6–21) postneonatal deaths; 4,600 (900–24,000) IQ points lost; and 1.4 (1.2–1.7) million days of work absences.
- As a result of the health impacts of Scenario 1, air pollution from these CFPPs will cost EUR 14 (9–23) billion.
- In the second scenario (Scenario 2), CFPPs follow an accelerated phase out where the capacity of electricity-only units (3,300 megawatts, MW) decreases by 26% by 2026; by 41% by 2030; and by 100% by 2035, and capacities for combined heat and power (CHP) and industrial units are fixed at present-days values throughout the time period.
- Under Scenario 2, air pollution from Bulgarian CFPPs decreases in line with decreased capacity, leading to a lower public health and economic burden.
- Compared to Scenario 1 where phase out is delayed until 2038, the accelerated phase out of Scenario 2 leads to lower pollutant levels, which prevents 3,300 premature deaths; 2,400 hospital admissions; 69,000 cases of asthma symptoms in children; 7,100 cases of bronchitis in children; 1,400 cases of chronic bronchitis in

adults; 610 low birth weights; 1,100 preterm births; 6 postneonatal deaths; 2,600 lost IQ points; and 740,000 work absences.

- The prevention of these health outcomes corresponds to an economic saving of EUR 9 billion.
- In the third scenario (Scenario 3), the accelerated phase out is extended to include electricity-only and CHP units, where the percentage reductions for electricity units outlined in Scenario 2 are applied to both electricity-only and CHP units, and industrial units maintain current power capacities throughout the time period.
- Compared to Scenario 1 where phase out is delayed until 2038, this accelerated phase out of Scenario 3 that includes electricity-only and CHP units prevents 3,600 premature deaths; 2,700 hospital admissions; 77,000 cases of asthma symptoms in children; 7,900 cases of bronchitis in children; 1,600 cases of chronic bronchitis in adults; 680 low birth weights; 1,230 preterm births; 7 postneonatal deaths; 2,900 lost IQ points;and 820,000 days of work absences.
- The prevention of these health outcomes corresponds to an economic saving of EUR 10 billion.
- Overall, we conclude that an accelerated phase out of Bulgaria's CFPPs will have huge benefits to air quality, public health, and the economy, including the prevention of thousands of deaths and saving billions of euros in health costs.

Contents

Introduction

Bulgaria is one of the most polluted countries in Europe. In Bulgaria, concentrations of nitrogen dioxide (NO_2), and particulate matter less than 10 µm (PM_{10}), and 2.5 µm ($PM_{2.5}$) exceed the guideline values set out by the World Health Organization (WHO) (European Environment Agency, 2023). Sofia and other major Bulgarian cities have some of the highest death rates due to exposure to air pollution among EU cities (Politico, 2022). Indeed, each year exposure to air pollution leads to around 15,000 deaths in Bulgaria (Tsanova et al., 2020; European Environment Agency, 2021; Guardian, 2023).

The public health impacts of air pollution have a devastating impact on the economy in Bulgaria. The economic costs are driven by a range of health issues, including the loss of life, work absences, and healthcare costs (e.g. medication). The annual economic damages due to air pollution reach EUR 2.5 million in Sofia, and account for up to 10% of GDP across the cities of Ruse, Shumen, Plovdiv (de Bruyn and de Vries, 2020). Of the high-skilled workforce in the economic hub of Sofia, air pollution is responsible for 46% of work absences, and 37% consider leaving due to air pollution (Deloitte, 2021). In addition, poor air quality has gathered media attention both domestically and internationally (New York Times, 2013; EuroNews, 2020).

In Bulgaria, coal-fired power plants (CFPPs) are a major source of air pollution, as well as the corresponding impact on human health and the economy. For instance, electricity and heat production accounts for 30 and 80% of Bulgaria's emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_X), respectively (European Environment Agency, 2023). Bulgaria has 10 CFPPs with a combined capacity of around 5,000 MW, including 5 electricity-only (3,930 MW); 4 CHP (935 MW); and 1 industrial (174 MW) CFPP.

The south-east region in Bulgaria, where the majority of coal capacity is concentrated, suffers from some of the highest levels of sulphur dioxide (SO_2) in Europe. Due to failing to address this air pollution issue for its citizens, the European Court of Justice (CJEU) ruled that Bulgaria breached EU rules (Balkan Green Energy News, 2022). In addition, recent research by the National Institute for Meteorology and Hydrology showed that air pollution in Sofia is not only affected by local sources, within the city, but also by two CFPPs located 30 and 70 km away (Hristova et al., 2020).

In order to meet the Paris Agreement and to limit the dangerous impacts of climate change, Bulgaria faces domestic and international pressures to phase out its coal-fired power plants, which are a major source of the nation's greenhouse gas emissions. However, citing energy security, conflict, and economic crises, the Bulgarian government has recently rolled back plans to phase out CFPPs, and is now proposing to start the phase-out as late as 2038 (EuroNews, 2023). In this study, we explore how the rollback of the CFPP phase-out will affect air quality, public health, and the economy in Bulgaria.

Results

Annual air quality impacts in the present-day

In the present-day, Bulgarian CFPPs have a major impact on air pollution, public health, and the economy. Emissions from Bulgarian CFPPs lead to the formation of regulated pollutants, including $PM_{2.5}$, NO_2, SO_2, and O_3. Figure 1 shows the distribution of $PM_{2.5}$ originating from Bulgarian CFPPs. Elevated concentrations (reaching 0.7 $\mu g/m^3$) of annual mean $PM_{2.5}$ are simulated around the locations of the power plants. However, as this pollutant can remain in the atmosphere for 1–2 weeks, elevated concentrations (> 0.1 $\mu g/m^3$) are sustained throughout the whole of Bulgaria, and even into neighbouring countries, including Serbia, North Macedonia, Greece, and Turkey. As a consequence, these power plants contribute to increased pollutant exposure for millions of humans. As a result of these pollutant levels, present-day air pollution from Bulgarian CFPPs leads to 333 (202–552) deaths each year (with the values in parentheses indicating the 95% confidence intervals). Overall, these deaths as well as other non-fatal illnesses cost EUR 742 (456–1,303) million each year. This is equivalent to 0.9% of Bulgaria's GDP, and is comparable to Bulgaria's military and defence budget (EUR 1.2 brillion – 1.5% of GDP).

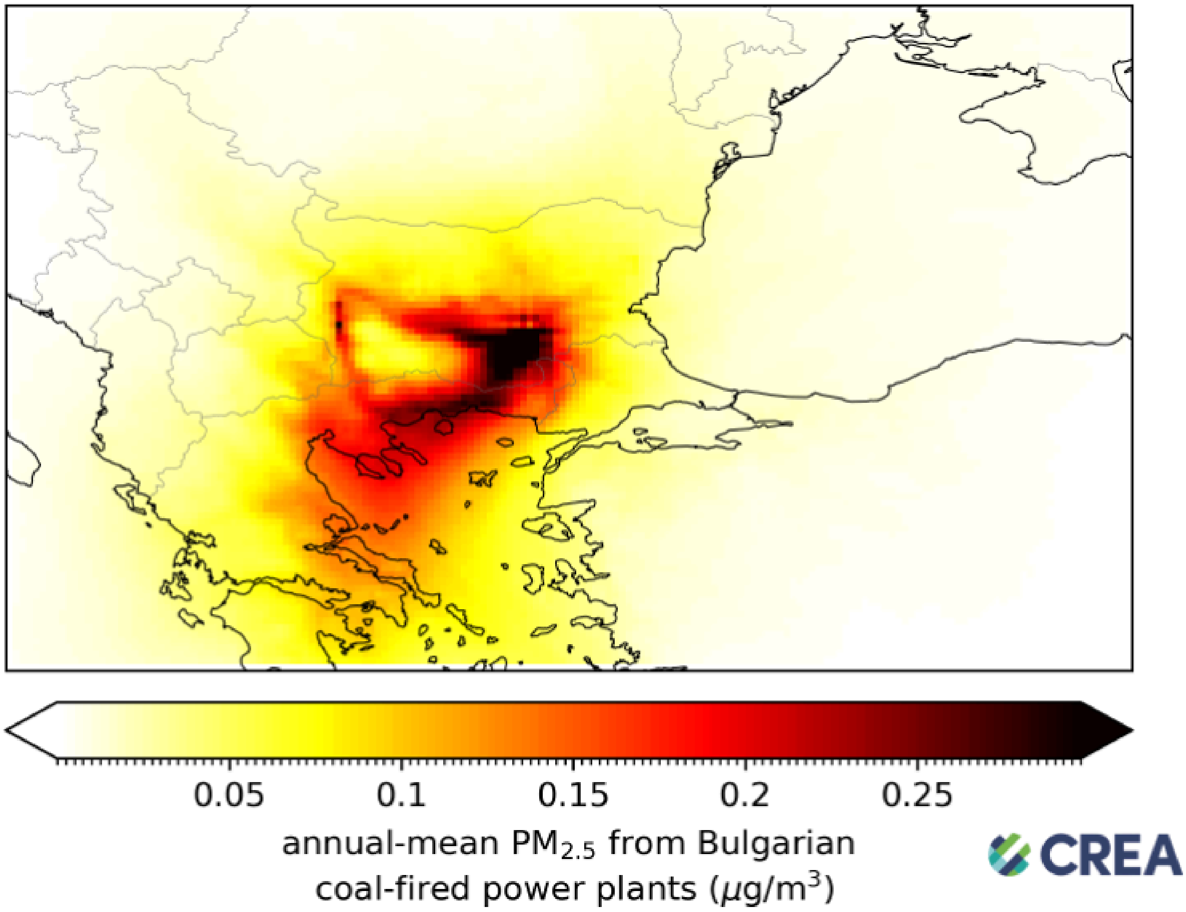

Figure 1. Annual mean $PM_{2.5}$ due to air pollution from Bulgarian CFPPs in the present-day (2023)

Note: simulated using the EMEP chemical-transport model.

Cumulative (2023–2038) air quality impacts under different phase-out scenarios

Table 1 shows a summary of the cumulative (2023–2038) health impacts due to air pollution from Bulgarian CFPPs. In Scenario 1, CFPPs are utilised until 2038 and air pollution will have a major impact on public health and the economy. Notably, this includes 5,500 (3,400–9,100) premature deaths; 4,600 (440–8,700) hospital admissions; 132,000 (29,000–237,000) cases of asthma symptoms in children; 13,600 (-3,600–30,800) cases of bronchitis in children; 2,700 (950–4,200) cases of bronchitis in adults; 1,150

(360–2,000) low birth weights; 2,100 (1,000–2,300) preterm births; 12 (6–21) postneonatal deaths; 4,600 (900–24,000) IQ points lost, and 1,400,000 (1,200,000–1,700,000) work absences. As a result of these health impacts, air pollution from these CFPPs will cost EUR 14 (9–23) billion.

Table 1. Three scenarios for cumulative health impacts (2023–2038) due to air pollution from Bulgarian coal-fired power plants

Effect	Scenario 1	Scenario 2	Scenario 3
All-cause mortality (premature deaths)	5,500 (3,400–9,100)	2,200 (1,300–3,700)	1,900 (1,100–3,100)
Hospital admissions (cases)	4,600 (440–8,700)	2,200 (250–4,100)	1,900 (220–3,601)
Asthma symptoms in asthmatic children (cases)	132,000 (29,000–237,000)	63,000 (14,000–114,000)	55,000 (12,000–100,000)
Bronchitis in children (cases)	13,600 (-3,600–30,800)	6,500 (-1,700–14,800)	5,700 (-1,500– 3,000)
Bronchitis in adults (cases)	2,700 (950–4,200)	1,300 (450–2,000)	1,100 (390–1,700)
Low birth weight (births)	1,150 (360–2,000)	540 (170–930)	470 (150–820)
Preterm births (births)	2,100 (1,000–2,300)	1,000 (480–1,000)	870 (420–920)
Post neonatal mortality (deaths)	12 (6–21)	6 (3–10)	5 (3–9)
Lost IQ (IQ points)	4,600 (900–24,000)	2,000 (400–11,000)	1,700 (300–8,800)
Work days lost (days)	1,400,000 (1,200,000–1,700,000)	660,000 (560,000 – 760,000)	580,000 (490,000–660,000)
Economic cost (EUR billion)	14 (9–23)	5 (3–9)	4 (3–8)

A faster phase-out of CFPPs will greatly reduce air pollution and lead to substantial benefits for public health and the economy. Figure 2 shows cumulative deaths due to exposure to air pollution from CFPPs across all three scenarios presented in this study. In Scenario 2, cumulative premature deaths due to air pollution from CFPPs will decrease by 60%, from 5,500 (3,400–9,100) to 2,200 (1,300–3,700), which corresponds to saving 3,300 lives. This pathway will also prevent 2,400 hospital admissions; 69,000 cases of asthma symptoms in children; 7,100 cases of bronchitis in children; 1,400 cases of chronic bronchitis in adults; 610 low birth weights; 1,100 preterm births; 6 postneonatal deaths; 2,600 lost IQ points, and 740,000 work absences.

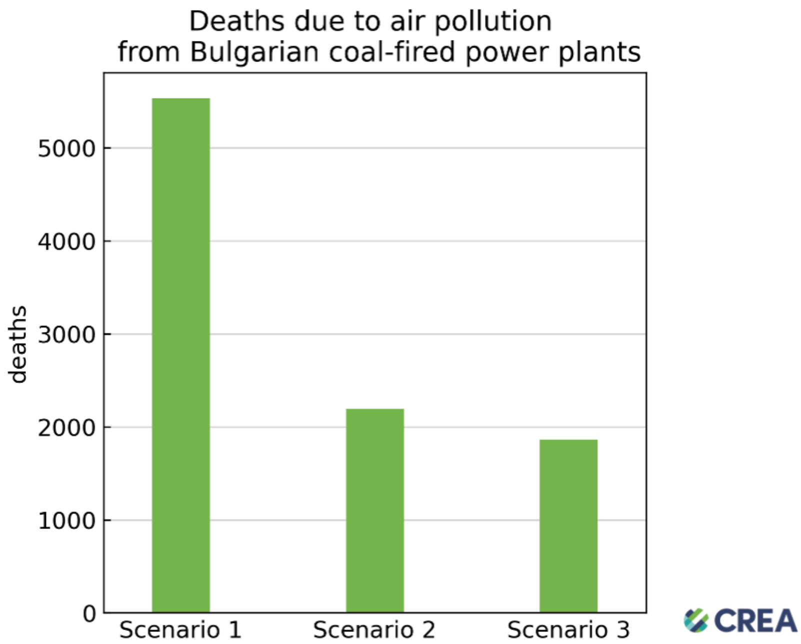

Figure 2. Premature deaths due to air pollution from Bulgarian CFPPs under three scenarios

Figure 3 shows the economic cost of air pollution from CFPPs under the three scenarios investigated in this study. We find that not only does Scenario 3 lead to a lower public health burden, but it also has a large benefit to the economy. Under Scenario 3, economic costs due to air pollution from CFPPs reduce by more than 60 % to EUR 5 billion, which corresponds to an economic saving of EUR 9 billion.

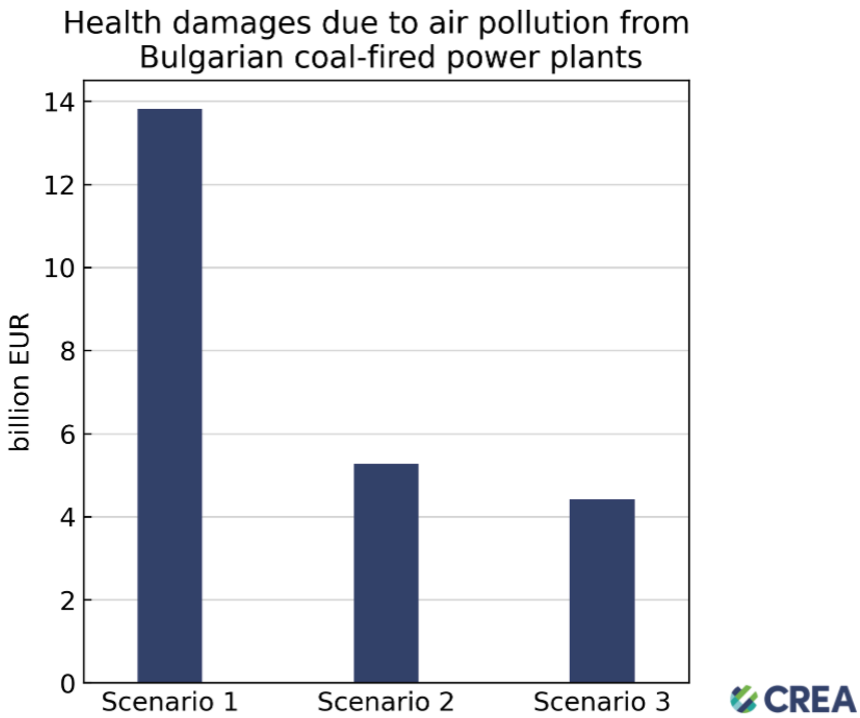

Figure 3. Health-related economic damages (billion EUR) of air pollution from Bulgarian CFPPs

An even faster phase-out that also includes both electricity and CHP CFPPs (Scenario 3) will lead to even larger air quality benefits. Compared to delaying phase-out until 2038 (Scenario 1), cumulative premature deaths due to air pollution from CFPPs decreased by 65%, from 5,500 (3,400–9,100) to 1,900 (1,100–3,100), which corresponds to saving 3,600 lives. This pathway will also prevent 2,700 hospital admissions, 77,000 cases of asthma symptoms in children, 7,900 cases of bronchitis in children, 1,600 cases of chronic bronchitis in adults, 680 low birth weights, 1,230 preterm births, 7 postneonatal deaths, 2,900 lost IQ points, and 820,000 work absences. Under this scenario, economic costs due to air pollution from CFPPs have reduced by 71 % to EUR 4 billion, which corresponds to an economic saving of EUR 10 billion.

Methodology

Coal power and emission scenarios

In this study, we explore three different coal-fired energy scenarios, as displayed in Figure 4. In the first scenario (Scenario 1), coal-fired power plants follow the delayed phase-out plan, which is currently being proposed by the Bulgarian government (EuroNews, 2023). In this scenario, capacities for six electricity-only (3,930 MW), four CHP (935 MW), and one industrial (174 MW) coal-fired power plant remain fixed at present-day values until 2038. In the second scenario (Scenario 2), we explore the accelerated phase-out of electricity-only coal-fired power plants, which is proposed by the Bulgarian government (Council of Ministers of the Republic of Bulgaria, 2023). In this scenario, capacities for electricity-only reduce by 26% to 2,900 MW by 2026; by 59% to 1,600 MW in 2030; and by 100% to 0 MW by 2035; and capacities for CHP (935 MW) and industrial (174 MW) remain fixed at present-day values. In the third scenario (Scenario 3), we explore an accelerated phase-out for both electricity-only and CHP units. In this scenario, the projected percentage reductions are applied to both electricity-only and CHP units, and industrial units remain constant. We do not explore the phase-out of industrial units in any scenario due to the absence of any strategy for decarbonisation of these units. In all three scenarios, facilities are phased out in the order from highest to lowest health impacts per unit of pollutant.

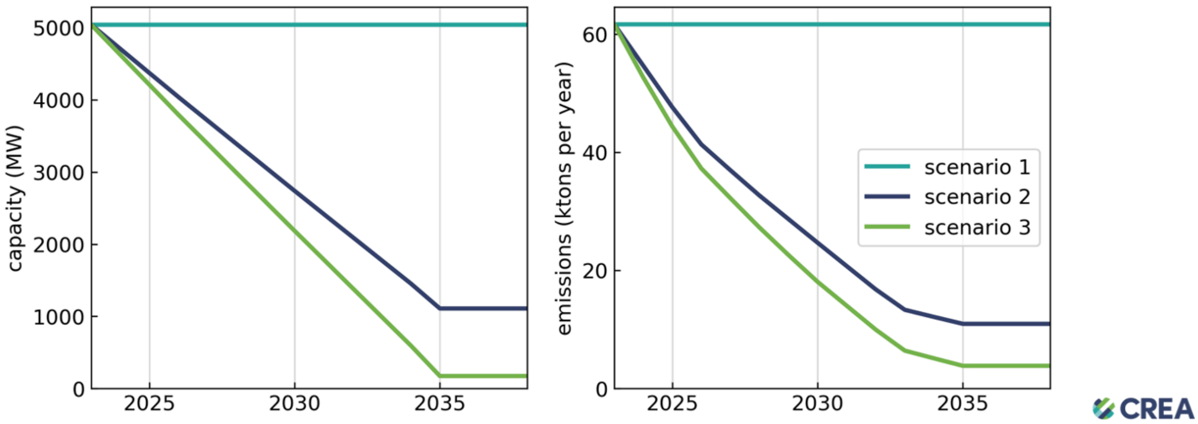

Figure 4. Total power capacity (MW) and total emissions (NO_X, SO_2, and PM_{10}) under three scenarios

For the present-day, pollutant emissions are either taken from Beyond Fossil Fuels (2023) or from the European Union's Pollutant Release and Transfer Register (PRTR) (European Union, 2023), depending on which database has the most recent emissions. Under the future scenarios, pollutant emissions are scaled proportional to the facility's changes in power capacity.

Atmospheric modelling

To simulate pollutant levels in the atmosphere, we use the atmospheric chemical-transport model for the European region developed under the European Monitoring and Evaluation Programme Meteorological Synthesizing Centre - West (EMEP MSC-W) of the Convention on Long-Range Transboundary Air Pollution (CLRTAP). Model code (version 5.0, Simpson et al. 2023) and the required meteorological data and other input datasets were provided by EMEP MSC-W and the Norwegian Meteorological Institute. These inputs include the baseline emissions inventory containing the emissions from all source sectors and locations. We used the “high-resolution” version of the model, with a horizontal resolution of 0.1x0.1 degrees (approximately 10 km).

Health and economic impact assessment

CREA has developed a detailed globally implementable health impact assessment (HIA) framework based on the latest science (Myllyvirta, 2020). This framework includes as complete a set of health outcomes as possible without obvious overlaps.

The emphasis is on outcomes for which incidence data is available at the national level from global datasets and outcomes that have high relevance for healthcare costs and labour productivity. These health endpoints were selected and quantified in a way that enables economic valuation, adjusted by levels of economic output and income in different jurisdictions.

For each evaluated health outcome, we have selected a concentration-response relationship that has been used to quantify the health burden of air pollution at the global level in peer-reviewed literature. This indicates that the evidence is mature enough to be applied across varying geographies and exposure levels. The calculation of health impacts follows a standard epidemiological calculation:

$$\Delta cases = Pop \times \sum_{age} \left[Frac_{age} \times Incidence_{age} \times \frac{RR_{c,age} - 1}{RR_{c,age}} \right],$$

Where:

Pop is the total population in the grid location;

age is the analysed age group. In the case of age-dependent concentration-response functions, a 5-year age segment; in other cases, the total age range to which the function is applicable;

$Frac_{age}$ is the fraction of the population belonging to the analysed age group;

Incidence is the baseline incidence of the analysed health condition;

c is the pollutant concentration with c_{base} referring to the baseline concentration or current ambient concentration; and,

$RR_{conc,\ age}$ is the function giving the risk ratio of the analysed health outcome at the given concentration for the given age group compared with clean air. In the case of a log-linear, non-age specific concentration-response function the RR function becomes:

$$RR(c) = RR_0 c - c_0 \Delta c_0 \ when\ c > c_0, \text{1 otherwise}$$

Where:

RR_0 is the risk ratio found in epidemiological research;

Δc_0 is the concentration change that RR_0 refers to; and,

c_0 is the assumed no-harm concentration - in general, the lowest concentration found in study data.

Data on the total population and population age structure was taken from the Global Burden of Disease results for 2019 (Murray et al., 2020), which was accessed by the Institute for Health Metrics and Evaluation (IHME, 2020). The spatial distribution of the population within each city and country, as projected for 2020, was based on the Gridded Population of the World v4 from the Center for International Earth Science Information Network (CIESIN, 2018).

Adult deaths were estimated using the risk functions developed by Burnett et al. (2018), as applied by Lelieveld et al. (2019). Deaths of small children under five years old from lower respiratory infections linked to $PM_{2.5}$ pollution were assessed using the Global Burden of Disease risk function for lower respiratory diseases (IHME, 2020). For all mortality results, cause-specific data was taken from the Global Burden of Disease project results for 2019 (IHME, 2020).

Health impact modelling projects the effects of pollutant exposure during the study year. Some health impacts are immediate, such as exacerbation of asthma symptoms and lost working days, whereas other chronic impacts may have a latency of several years. Concentration-response relationships for emergency room visits for asthma and work absences were based on studies that evaluated daily variations in pollutant concentrations and health outcomes; these relationships were applied to changes in annual average concentrations.

The development of the health impacts into the future took into account projected changes in population, population age structure, and mortality by age group, based on the (UNDP, 2022) World Population Prospects Medium Variant. This factors in the expected reduction in baseline infant mortality and increase in deaths from chronic diseases in older adults as a part of the population and epidemiological transitions and improvements in health care.

Appendix

Table A1. Capacities of the studied plants and their types

Facility	Type	Capacity
Maritsa 3	Electricity	120
Bobov Dol	Electricity	630
AES Maritsa Iztok 1	Electricity	670
Maritsa Iztok 2	Electricity	1,602
ContourGlobal Maritsa Iztok 3	Electricity	908
Deven	Industrial	174
Republika (Pernik)	CHP	130
Ruse Iztok	CHP	400
Brikel	CHP	360
Sliven	CHP	45
Total	-	5,039

Table A2. Power capacities (MW) for Bulgarian coal-fired power plants under three phase-out scenarios

Time horizon	Electricity-only	CHP	Industrial
Scenario 1			
2023	3,930 MW (100%)	935 MW (100%)	174 MW (100%)
2026	3,930 MW (100%)	935 MW (100%)	174 MW (100%)

2030	3,930 MW (100%)	935 MW (100%)	174 MW (100%)
2035	3,930 MW (100%)	935 MW (100%)	174 MW (100%)
Scenario 2			
2023	3,930 MW (100%)	935 MW (100%)	174 MW (100%)
2026	2,900 MW (74%)	935 MW (100%)	174 MW (100%)
2030	1,600 MW (41%)	935 MW (100%)	174 MW (100%)
2035	0 MW (0%)	935 MW (100%)	174 MW (100%)
Scenario 3			
2023	3,930 MW (100%)	935 MW (100%)	174 MW (100%)
2026	2,900 MW (74%)	690 MW (74%)	174 MW (100%)
2030	1,600 MW (41%)	381 MW (41%)	174 MW (100%)
2035	0 MW (0%)	0 MW (0%)	174 MW (100%)

Note: Values in parentheses indicating power capacity relative to 2030 (%).

Table A3. Annual present-day (2023) impacts of air pollution from Bulgarian coal-fired power plants on premature mortality and the economy

Effect	Estimate
All-cause mortality (deaths)	333 (202–552)
Economic cost (EUR million)	742 (456–1,303)

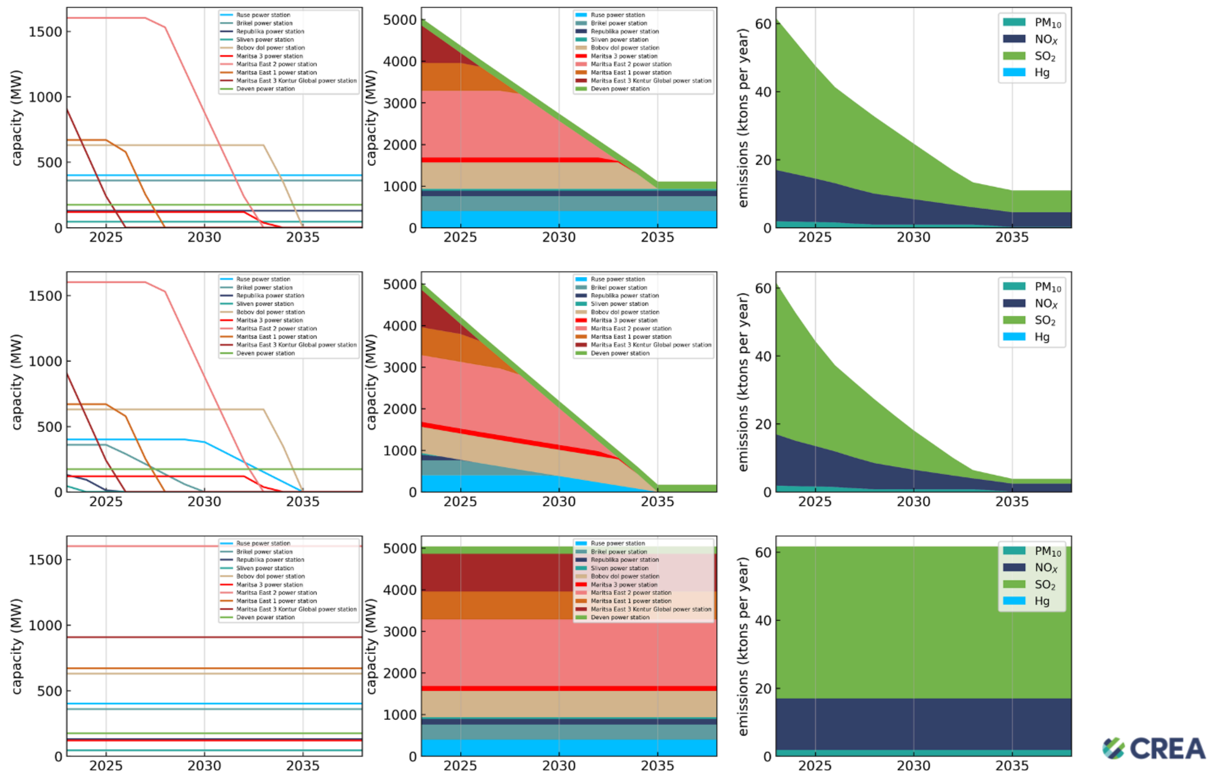

Figure A1. Facility-level power capacity and emission trends under the three scenarios investigated in this study

References

Balkan Green Energy News (2022). Bulgaria is guilty for air pollution rules European Court of Justice. https://balkangreenenergynews.com/bulgaria-is-guilty-for-air-pollution-rules-european-court-of-justice/#:~:text=The%20European%20Court%20of%20Justice%20has%20ruled%20that%20people%20in,the%20Maritsa%20Iztok%20complex%2C%20ClientEarth

Beyond Fossil Fuels (2023). Beyond Fossil Fuels: European Coal Plant Database. https://beyondfossilfuels.org/coal/

Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope, C. A., Apte, J. S., Brauer, M., Cohen, A., Weichenthal, S., Coggins, J., Di, Q., Brunekreef, B., Frostad, J., Lim, S. S., Kan, H., Walker, K. D., Thurston, G. D., Hayes, R. B., … Spadaro, J. V. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. Proceedings of the National Academy of Sciences, 115(38), 9592–9597. https://doi.org/10.1073/pnas.1803222115

CIESIN. (2018). Gridded Population of the World, Version 4 (GPWv4): Population Density Adjusted to Match 2015 Revision UN WPP Country Totals, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC), 2018. https://doi.org/10.7927/H4F47M65

Council of Ministers of the Republic of Bulgaria. (2023). Правителството актуализира Пътната карта за климатична неутралност. (Published on 6 Oct 2023). https://government.bg/files/common/pk.pdf

Deloitte. (2021). Impact of Air Pollution on Career Decisions of the Highly-Skilled Workforce in Sofia. https://s40026.pcdn.co/wp-content/uploads/Deloitte-CAF-report_v7_compressed.pdf

De Bruyn, S. & de Vries, J. (2020). Health costs of air pollution in European cities and the linkage with transport. Delft, CE Delft, October 2020. https://cedelft.eu/wp-content/uploads/sites/2/2021/03/CE_Delft_190272_Health_costs_of_air_pollution_in_European_cities_and_the_linkage_with_transport_Def.pdf

Euronews. (2020). Bulgaria citizens concerned about rising air pollution amid coronavirus crisis. (Published on 10 Oct 2020). https://www.euronews.com/2020/12/10/bulgaria-citizens-concerned-about-rising-air-pollution-amid-coronavirus-crisis

Euronews (2023). Bulgaria rolls back plans to phase out coal amid fears over energy and job security. https://www.euronews.com/green/2023/01/13/bulgaria-rolls-back-plans-to-phase-out-coal-amid-fears-over-energy-and-job-security

European Environment Agency (EEA). (2023). Europe's Air Quality Status 2023. (Published 24 Apr 2023). https://www.eea.europa.eu/publications/europes-air-quality-status-2023

European Environment Agency (EEA). (2021). Bulgaria — Air Pollution Country Fact Sheet. https://www.eea.europa.eu/themes/air/country-fact-sheets/2021-country-fact-sheets/bulgaria

European Union (2023), The European Pollutant Release and Transfer Register (E-PRTR), https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/european-pollutant-release-and-transfer-register-e-prtr_en.

Guardian (2023). Revealed: almost everyone in Europe is breathing toxic air. https://www.theguardian.com/environment/2023/sep/20/revealed-almost-everyone-in-europe-breathing-toxic-air?CMP=Share_iOSApp_Other

Guillot, L. (2022). Sofia Looks to Make Pollution Cuts 'Trendy'. *Politico*. (Published on 27 Oct 2022). https://www.politico.eu/article/sofia-bulgaria-pollution-cuts-eu-trendy/

Hakim, D. (2013). Bulgaria's Air Is Dirtiest in Europe, Study Finds, Followed by Poland. *The New York Times.* https://www.nytimes.com/2013/10/15/business/international/bulgarias-air-is-dirtiest-in-europe-study-finds-followed-by-poland.html

Hristova, E., Veleva, B., Georgieva, E., & Branzov, H. (2020). Application of Positive Matrix Factorization Receptor Model for Source Identification of PM10 in the City of Sofia, Bulgaria. *Atmosphere*, *11*(9), 890. https://doi.org/10.3390/atmos11090890

Institute for Health Metrics and Evaluation (IHME) (2020). GBD Results.

http://ghdx.healthdata.org/gbd-results-tool

Lelieveld, J., Klingmüller, K., Pozzer, A., Burnett, R. T., Haines, A., & Ramanathan, V. (2019). Effects of fossil fuel and total anthropogenic emission removal on public health and climate. Proceedings of the National Academy of Sciences, 116(15), 7192–7197. https://doi.org/10.1073/pnas.1819989116

Murray, C. J. L., Aravkin, A. Y., Zheng, P., Abbafati, C., Abbas, K. M., Abbasi-Kangevari, M., Abd-Allah, F., Abdelalim, A., Abdollahi, M., Abdollahpour, I., Abegaz, K. H., Abolhassani, H., Aboyans, V., Abreu, L. G., Abrigo, M. R. M., Abualhasan, A., Abu-Raddad, L. J., Abushouk, A. I., Adabi, M., … Lim, S. S. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. The Lancet, 396(10258), 1223–1249. https://doi.org/10.1016/S0140-6736(20)30752-2

Myllyvirta, L. (2020). Quantifying the Economic Costs of Air Pollution from Fossil Fuels. Centre for Research on Energy and Clean Air. https://energyandcleanair.org/publication/quantifying-the-economic-costs-of-air-pollution-from-fossil-fuels/

New York Times (2013). Bulgaria's air is dirtiest in Europe, study finds, followed by Poland. https://www.nytimes.com/2013/10/15/business/international/bulgarias-air-is-dirtiest-in-europe-study-finds-followed-by-poland.html

Politico. (2022). Sofia looks to make pollution cuts 'trendy'. https://www.politico.eu/article/sofia-bulgaria-pollution-cuts-eu-trendy/

Simpson, D., van Caspel, W., Benedictow, A., Fagerli, H., Jonson, J. E., Tsyro, S., Valdebento, A., & Wind, P. (2023). Updates to the EMEP/MSC-W model, 2022–2023, in: Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components. EMEP Status Report 1/2023, 159–179. https://emep.int/publ/reports/2023/EMEP_Status_Report_1_2023.pdf

Tsanova, D., Georgieva, S. & Kamburova, M. (2020). Health impacts of air pollution in Bulgaria. *European Journal of Public Health*. Volume 30, Issue Supplement_5, September 2020. https://doi.org/10.1093/eurpub/ckaa166.078

UNDP. (2022). World Population Prospects—Population Division—United Nations. https://population.un.org/wpp/Download/Standard/MostUsed/