TRENDS IN AIR QUALITY AND HEALTH IN BULGARIA

A STATE OF GLOBAL AIR SPECIAL REPORT

HEI

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WHAT IS THE STATE OF GLOBAL AIR?

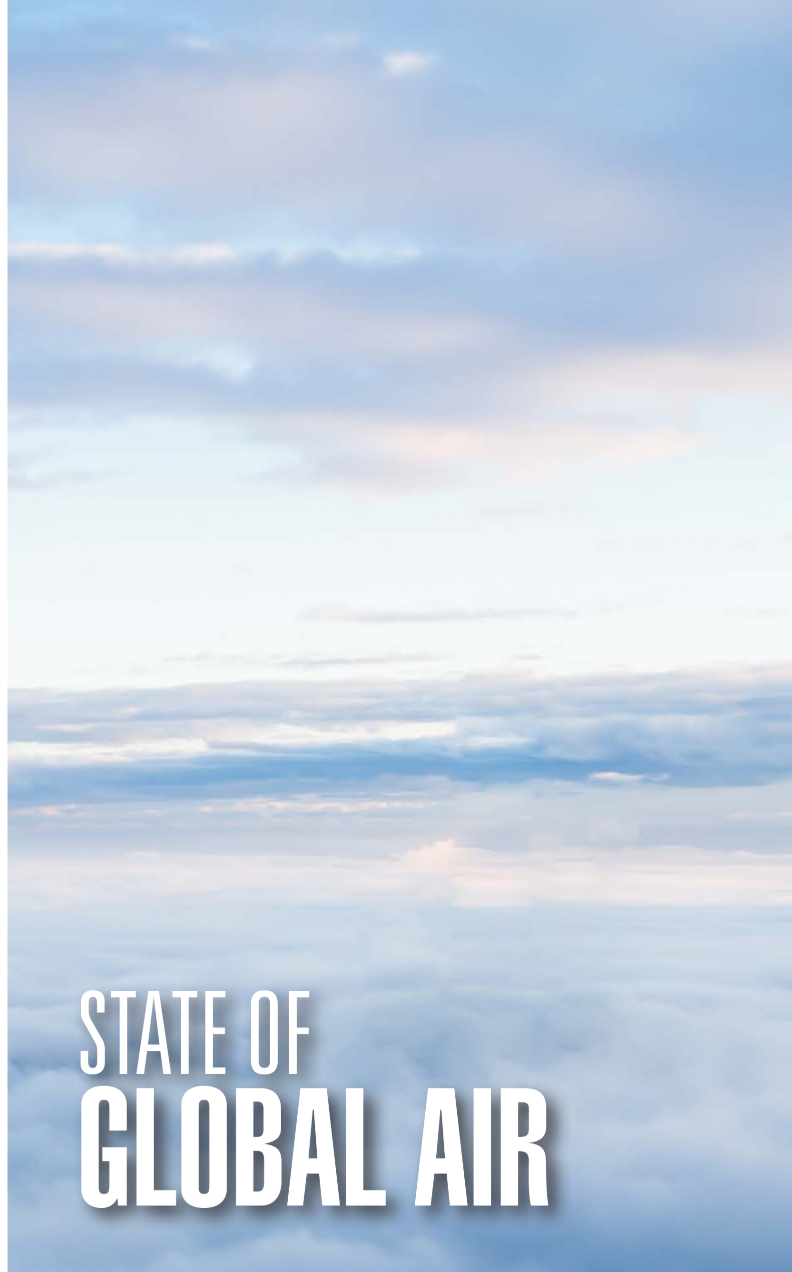
The *State of Global Air* report and interactive website offer a comprehensive analysis of the levels and trends in air quality and health for every country in the world. They are produced annually by the Health Effects Institute and the Institute for Health Metrics and Evaluation's (IHME's) Global Burden of Disease (GBD) project and are a source of objective, high-quality, and comparable air quality data and information.

WHO IS IT FOR?

The report and website are designed to give citizens, journalists, policymakers, and scientists access to reliable, meaningful information about air pollution exposure and its health effects. These resources are free and available to the public.

ABOUT THIS REPORT

This report provides an overview of the state of air quality and its impacts on the health of populations in Bulgaria. We draw on data from the GBD Study 2019 as well as a recent global assessment on sources of air pollution (McDuffie et al. 2021) to discuss trends in air pollution and the associated disease burden.



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INTRODUCTION

Globally, air pollution is the leading environmental risk factor for public health and is associated with significant health, economic, and social costs. These costs are often distributed inequitably across regions and communities. In 2019 alone, exposure to air pollution contributed to 6.67 million deaths (uncertainty interval [UI]: 5.90–7.49), which is nearly 12% of the total global deaths and is a disease burden surpassed only by high blood pressure, tobacco use, and poor diet. The total welfare losses ($PM_{2.5}$ and ozone) were estimated to cost Bulgaria approximately EUR 6 billion in 2017, representing 13% of the nation's gross domestic product (OECD 2020).

Accession into the EU in 2007, recent growth in public awareness, and a push for clean air have spurred demand for additional data on air quality and health information. Increasingly, readily accessible air pollution data from citizen science monitoring networks (e.g., *Air Bulgaria*), especially in major cities, has empowered the public to demand improved air quality. The public pressure has been strongest in Sofia, the capital city, where most extensive air quality measures have been implemented. Since 2015, there have been positive trends toward compliance across the country. However, sulfur dioxide (SO_2) is a persistent issue in one municipality (Galabovo) and again increased in another (Dimitrovgrad), both in the southeastern part of the country where lignite coal power plants are located. In addition, concentrations of coarse and fine particulate matter (PM_{10} and $PM_{2.5}$, respectively), and polycyclic aromatic hydrocarbons (PAHs) are elevated in most municipalities where monitors are deployed, and nitrogen dioxide (NO_2) is sporadically elevated in Plovdiv (World Bank 2019; ECAC 2020).

Air pollution was the 7th leading risk factor for deaths in Bulgaria in 2019.

WHAT THIS REPORT ADDS

This report provides an overview of the trends and patterns of air quality and its impacts on health in Bulgaria using data from the Global Burden of Disease (GBD) Study 2019 and HEI's *State of Global Air* report. It is designed to present the latest data on air pollution exposures, key sources, and the related health impacts, including the disease burden across age groups. It is one of three reports published by the Health Effects Institute on the topic of air quality and health in Southeast Europe (HEI 2022a, in press).

The GBD Study is a unique resource, where high-quality and internally consistent state-of-the-art methods have been applied to estimate current status and yearly trends in exposures and burden of disease from 87 risk factors or groups of factors in 204 countries and territories. To learn more, please visit *http://www.healthdata.org/gbd/2019*. We also draw on a first of its kind, recent global assessment (McDuffie et al. 2021) to discuss the major air pollution sources in the region and the related disease burden from these sources.

For detailed data, figures, and factsheets on air quality and health for Bulgaria and other countries, visit *https://www.stateofglobalair.org/*.

Legislation Related to National Air Quality

The EU member states must be in compliance with the relevant EU legislation on air quality, namely the Ambient Air Quality Directives (EP 2020) and the National Emissions Ceilings Directive (EEA 2016). Bulgaria's National Development Programme 2020, as well as the goals for the National Development Program 2030, define air quality as a national priority with a focus on (fine) particulate matter (PM) concentrations. National ambient air quality in Bulgaria is regulated by the Environmental Protection Act and the Clean Ambient Air Act, and although implementation power of these state policies rests with the Ministry of Environment and Waters in coordination with the Minister of Health, the legal responsibility sits at the municipal level. Bulgaria is divided into six regions for air quality management, and in areas where a breach of air quality standards is found, municipal mayors must draft and implement an Air Quality Program to be adopted by the municipal council (ECAC 2020).

The government adopted two national level air quality management programs in 2019 — the National Air Quality Improvement Program and the National Air Pollution Control Program —that establish the main sources of PM as residential heating and transport, particularly pre-EURO 2 (diesel) cars, which make up over 40% of the Bulgaria's passenger fleet. The programs stipulate that municipalities need to phase out solid fuel stoves and other appliances used for household heating that do not conform to EU's Ecodesign standards and strengthen regulations on technical inspections of motor vehicles. Other key measures include solid fuel standards, earlier adoption of Ecodesign standard, stricter control of vehicles on the road, and low emission zones. National legislation on industrial sources includes ordinances on limiting emissions for SO_2, nitrogen oxides (nitrogen oxide and NO_2, referred to as NO_x), and dust, and under the EU Directive on Integrated Pollution Prevention and Control, industrial plants must apply for emission permits (ECAC 2020). In 2017, the European Court of Justice ruled against Bulgaria for exceeding PM_{10} (annual and daily) limit values. Bulgaria is facing financial penalties as of December 2020, when the European Commission referred the country to European Court of Justice for not implementing the 2017 court decision (EC 2020a). Additionally in 2021, two long-standing legal cases brought by citizens and nongovernmental organizations came to resolution in Plovdiv and Sofia. The court rulings set a 1-year deadline on both cities to achieve air quality norms and implement concrete measures to protect the health of citizens. These cases also pushed the administration to increase efforts toward control of air pollution (Grossberndt et al. 2021).

EXPOSURE TO AIR POLLUTION

Air pollution is a complex mixture of particles and gases, whose sources and composition vary spatially and temporally. Key pollutants of interest include PM_{10}, $PM_{2.5}$, NO_x, ozone, carbon monoxide, and SO_2. Household air pollution, a mixture of particles and gases resulting from incomplete combustion of fuels in the home, is also of concern due to the proximity of the source to humans and the potential for high exposures, and due to its large contribution to outdoor air pollution. Exposure to these pollutants contributes to the disease burden of air pollution. As such, knowledge of trends of different pollutants is important to estimate the burden attributable to air pollution in each population and around the world.

In this section, we present an overview of current levels of key air pollutants at present and of their long-term trends in Bulgaria using data from the GBD 2019 study.

LEVELS AND TRENDS

Ambient $PM_{2.5}$

Ambient fine particle air pollution refers to $PM_{2.5}$ (i.e., particles measuring less than 2.5 micrometers in aerodynamic diameter and less than a 30th of the diameter of a human hair). These particles are emitted from cars, coal-burning power plants, industrial activities, homes burning coal and wood for heating or cooking, waste burning, and other human activities and natural sources. Fine particles are also formed in the atmosphere from gaseous air pollutants, such as nitrogen or sulfur oxides. Although exposures to smaller and larger airborne particles can both be harmful, studies have shown that among air pollutants, high $PM_{2.5}$ exposure over several years is the most consistent and robust predictor of mortality and morbidity due to cardiovascular, respiratory, and other types of diseases. Such small particles can be suspended in the air for days and be transported by the wind over thousands of kilometers. These particles penetrate deep into the lungs.

Despite reductions in the last decade, annual $PM_{2.5}$ concentrations in Bulgaria remain among the highest in Europe.

Annual mean $PM_{2.5}$ exposure in Bulgaria in 2019 was 19.4 µg/m³ (UI: 18.3–20.5 µg/m³), broadly in line with estimates from the European Environment Agency (EEA) and World Health Organization (WHO) (HEI 2022; EEA 2020; WHO 2021). Although $PM_{2.5}$ levels in Bulgaria are lower than the EU $PM_{2.5}$ air quality limit value of 25 µg/m³, they remain higher than the updated annual WHO guideline of 5 µg/m³ as well as the European Union (EU-28)[1] average $PM_{2.5}$ concentration of 11.4 (95% UI: 11.3–11.6). In Southeast Europe, annual 2019 average $PM_{2.5}$ levels range between 15.7 µg/m³ in Romania (UI: 14.7–16.9 µg/m³), and 30.3 µg/m³ in North Macedonia (UI: 27.4–33.1 µg/m³).

These data indicate that all of Bulgaria's population lives in areas where $PM_{2.5}$ levels exceed the current annual WHO guideline (5 µg/m³); a majority of the population (88%) also lives in areas that exceed the third interim target (15 µg/m³)[2] (for information on methods, see *https://www.stateofglobalair.org/data/estimate-exposure*).

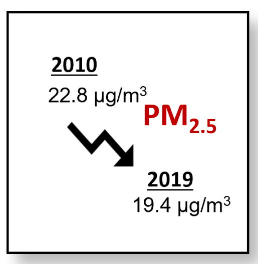
100% of Bulgaria's population lives in areas that exceed the WHO Air Quality Guideline

88% of Bulgaria's population lives in areas that exceed Interim Target 3 (15 µg/m³)

6% of Bulgaria's population lives in areas that exceed Interim Target 2 (25 µg/m³)

0% of Bulgaria's population lives in areas that exceed Interim Target 1 (35 µg/m³)

In the last decade, Bulgaria has made progress on reducing exposure to $PM_{2.5}$; between 2010 and 2019, $PM_{2.5}$ concentrations decreased by 3.40 µg/m³ (14.9%), down from 22.8 µg/m³ (UI: 21.6–24.1 µg/m³) (see Figure 1). In fact, in 2019, nine out of the ten stations in Bulgaria measuring $PM_{2.5}$ were compliant with the $PM_{2.5}$ limit value. However, two monitors, one in Sofia and one in Pernik, did not cover the minimum data coverage requirements in 2019 (ECAC 2020).



Although annual average levels have improved, wintertime levels rise to much higher levels each year. Monthly $PM_{2.5}$ concentrations in Sofia and Plovdiv — the two largest cities in the country — are much higher during the winter season. $PM_{2.5}$ levels start to rise in September and October, and the highest levels are typically observed in the month of January (Figure 2). In Varna and Stara Zagora, the levels are more stable throughout the year, and although $PM_{2.5}$ levels are similar to those in Sofia and Plovdiv during the summer months (May–August), con-

Exposures to $PM_{2.5}$ are highest in the winter months, especially in the two largest cities, Sofia and Plovdiv.

[1] EU-28 is the abbreviation of European Union (EU), including the United Kingdom.

[2] Four interim target levels were set by the WHO for attaining their air quality guideline of an annual average $PM_{2.5}$ concentration of 5 µg/m³. The interim targets are set at progressively lower concentrations: IT-1, 35 µg/m³; IT-2, 25 µg/m³; IT-3, 15 µg/m³; and IT-4, 10 µg/m³ (WHO 2021).

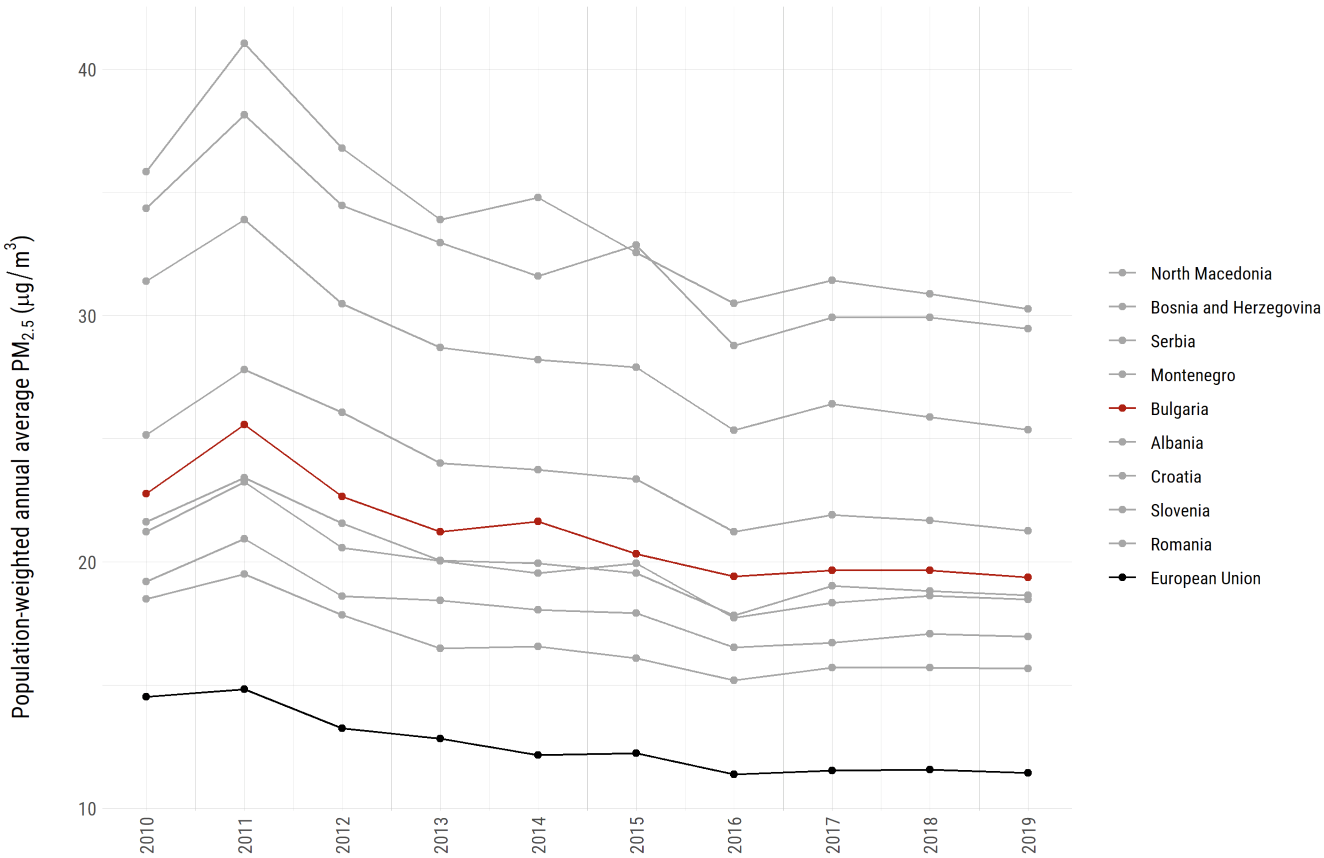


FIGURE 1 Trends in population-weighted annual average $PM_{2.5}$ exposure (µg/m³) in Bulgaria, Southeast Europe and EU-28, 2010–2019. Visit *https://www.stateofglobalair.org/data* to explore data.

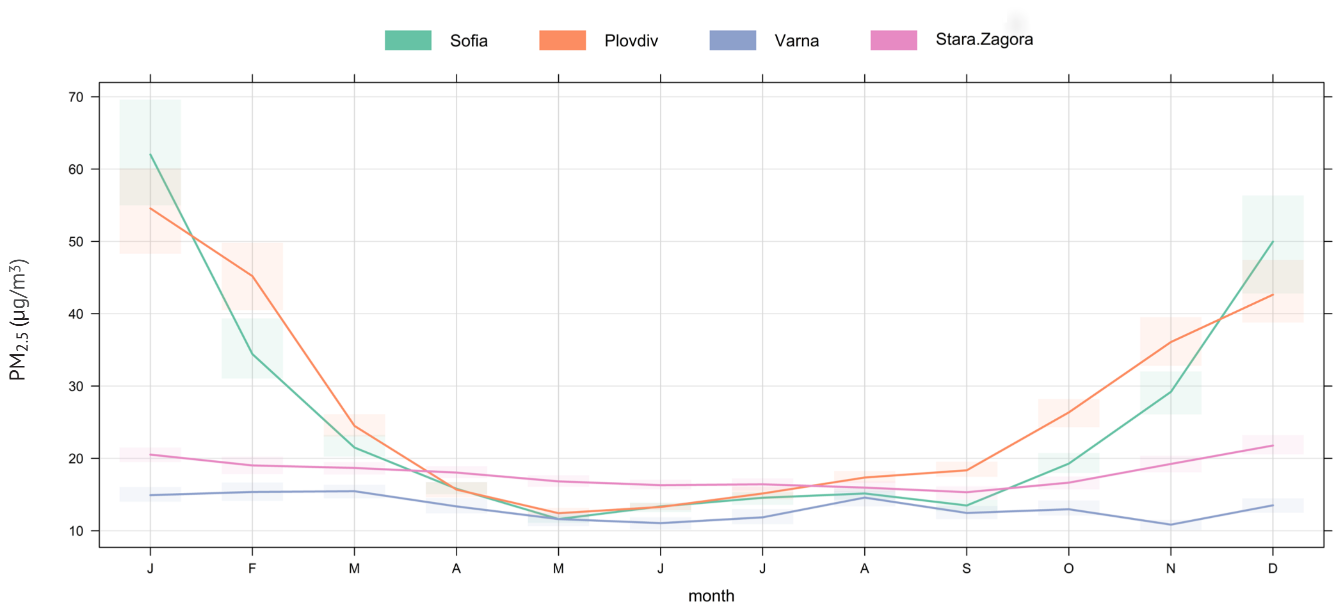


FIGURE 2 Monthly mean $PM_{2.5}$ concentrations (µg/m³) across four major cities in Bulgaria based on data collected by the Bulgarian Executive Environment Agency between 2013–2019 (Source: Bulgarian Executive Environment Agency, Dzhambov AM, personal communication, August 2021).

centrations can measure up to three times lower compared to Sofia and Plovdiv during winter season. Overall, EEA data ranked air quality for the Bulgarian cities of Plovdiv, Stara Zagora, Veliko Tarnovo, Ruse, and Varna as "poor" for 2019 and 2020 (EEA 2021).

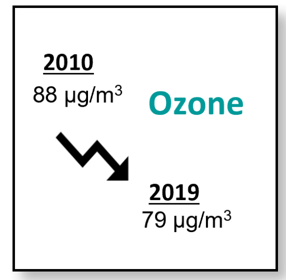
Ozone

Ground-level, or tropospheric, ozone is a highly reactive pollutant that is not released directly into the air but is formed through complex chemical interactions between NO_x and volatile organic compounds (VOCs) in the presence of sunlight. NO_x and VOCs are both produced by a variety of human activities: NO_x are emitted from the burning of fossil fuels (oil, gas, and coal) in cars, power plants, industrial boilers, and home heating systems, whereas VOCs are also emitted by cars as well as through oil and gas extraction and processing and other industrial activities. VOCs are also naturally emitted from some species of trees and other plants. Given these sources and the fact that NO_2 scavenges/titrates ozone, especially along roadways, NO_2 is typically higher in urban areas, while ozone is found in higher concentrations in suburban and rural areas. Although not directly comparable, the EU target value for short-term ozone (using a maximum daily 8 hour mean) is 120 µg/m³. The WHO's ozone air quality guideline is 100 µg/m³ for the short-term daily maximum 8-hour mean and 60 µg/m³ for the long-term as the peak season (6 months) mean of daily maximum 8-hour means.

Ozone exposure has decreased in the last decade.

In 2019, the population-weighted average seasonal 8-hour maximum ozone exposure in Bulgaria in was 79.4 µg/m³ (UI: 77.8–80.9 µg/m³), close to the average for the region, where ozone concentrations range from 65.3 µg/m³ in Romania (UI: 63.9–66.6 µg/m³) to 100.7 µg/m³ (UI: 98.8–102.7 µg/m³) in Slovenia. This level is also comparable to the EU-28 average of 83.5 µg/m³ (95% UI: 83.3–83.7 µg/m³). Ozone exposure decreased by 8.20 µg/m³ over the last decade, down from 87.6 (UI: 86.6–88.8) in 2010[3] (Figure 3).

Almost all of Bulgaria's population (99%) lives in areas where ozone levels exceed the current long-term WHO guideline of 60 µg/m³, and a majority (84%) lives in areas that exceed the second interim target of 70 µg/m³.



Monthly trends in ozone levels across four cities in Bulgaria — Sofia,

[3] All GBD estimates for ozone have been converted (1 ppb = 1.96 µg/m³ for 25°C). *https://uk-air.defra.gov.uk/assets/documents/reports/cat06/0502160851_Conversion_Factors_Between_ppb_and.pdf.*

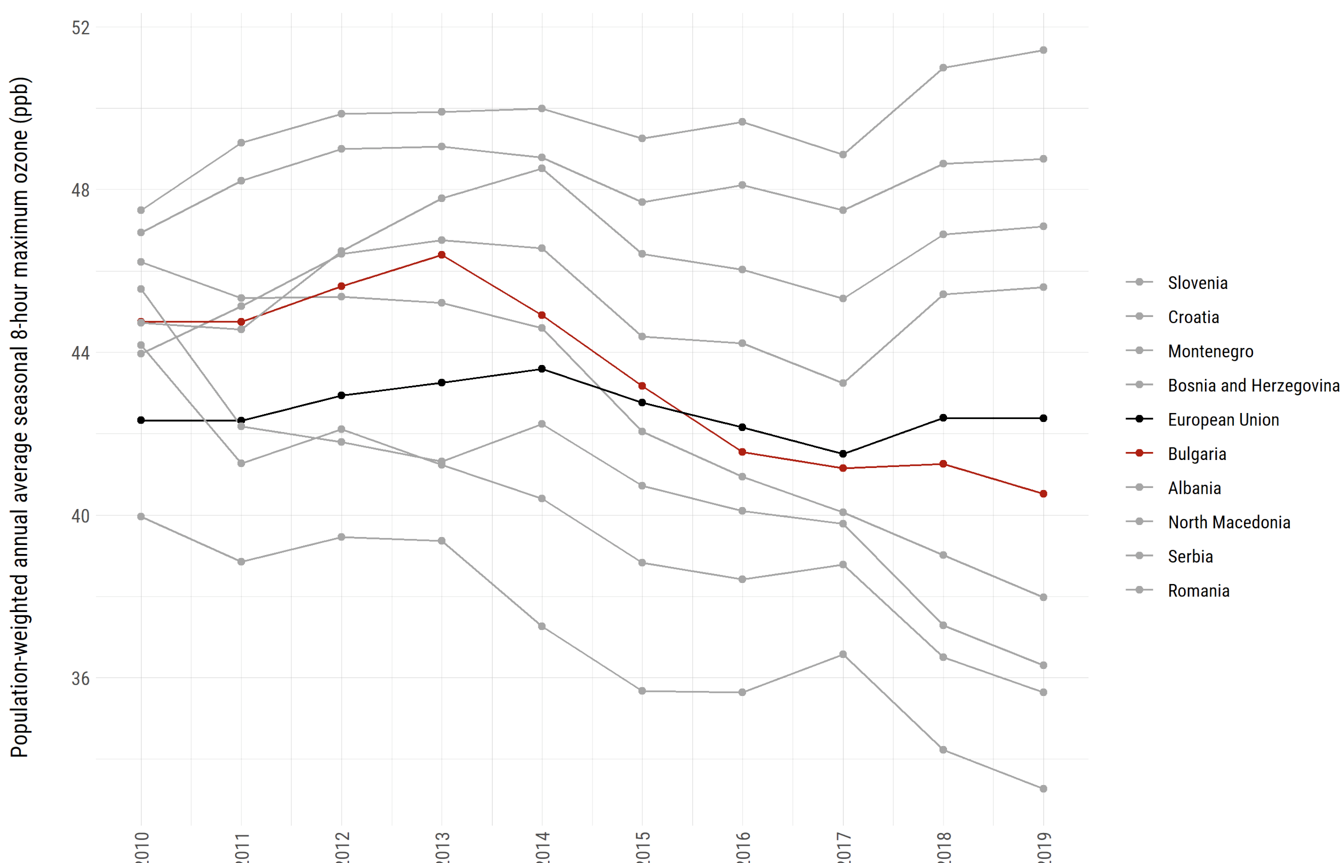


FIGURE 3 Trends in population-weighted annual average seasonal 8-hour daily maximum ozone exposures (ppb) in Bulgaria, Southeast Europe and EU-28, 2010–2019 (HEI 2020). Visit *https://www.stateofglobalair.org/data* to explore data.

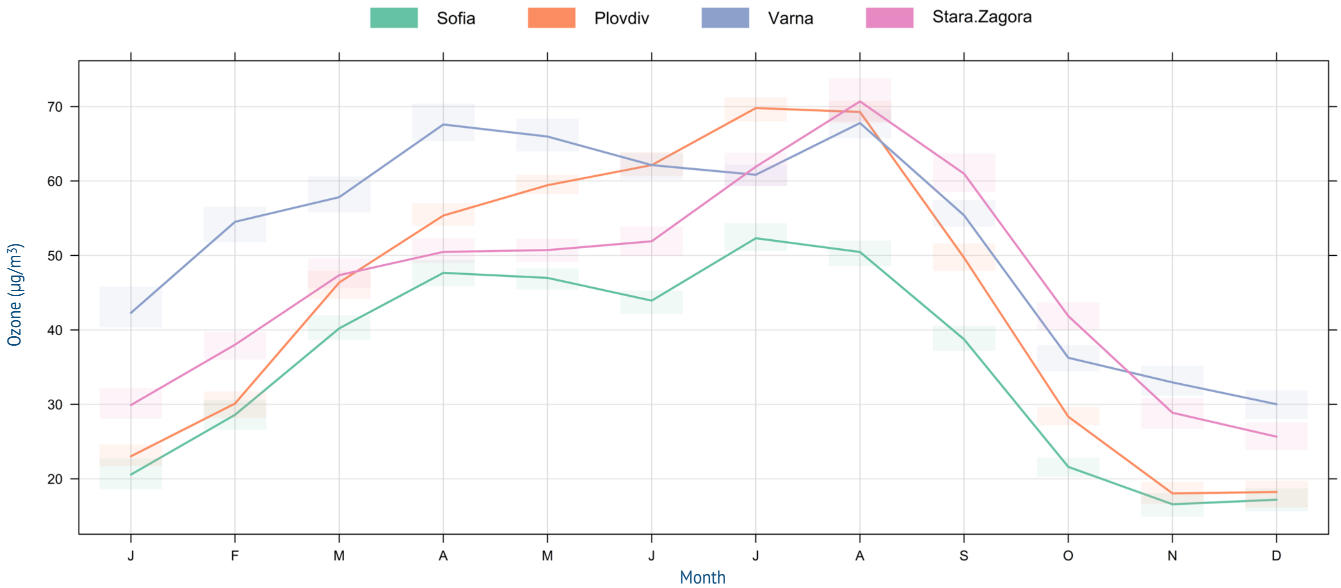


FIGURE 4 Average monthly mean ozone concentrations averaged for 2013–2019 across four cities in Bulgaria (µg/m3) (Source: Bulgarian Executive Environment Agency, Dzhambov AM, personal communication, August 2021).

Plovdiv, Varna, and Stara Zagora — peak substantially in the summer months and decline in the winter months (Figure 4), in stark contrast with the trends for $PM_{2.5}$ levels. The highest ozone concentrations occur in July or August and are similar in Plovdiv, Varna, and Stara Zagora but lower in Sofia.

Household Air Pollution from Use of Solid Fuels for Cooking

Household air pollution results from the combustion of solid fuels (such as coal, lignite, charcoal, wood, agricultural residue, and animal dung, as well as waste) for heating or cooking using open fires or stoves with limited ventilation. Burning these fuels produces an array of pollutants that may harm human health, including $PM_{2.5}$, black carbon, carbon monoxide, PAHs, and other carcinogenic compounds. Of note, GBD only includes the role of burning solid fuels for cooking in its estimates of exposure to household air pollution, and these exposures are estimated in terms of $PM_{2.5}$ exposures based on the proportion of a country's population that relies on solid fuel for cooking combined with evidence from household and personal exposure measurement studies.

> Although reliance on solid fuels for cooking has decreased in the last decade, nearly 20% of the country's population continues to rely on solid fuels for cooking.

In Bulgaria, 19.7% (UI: 10.9–22.3%) of the population relies on solid fuels for cooking. Although this is higher than the EU-28 average of 2.66% (95% UI: 2.13–3.35%), Bulgaria has expanded access to cleaner fuels for cooking over several years, which has resulted in a modest decrease of 2.5% percent of the population relying on solid fuels for cooking, down from 22.2% in 2010 (Figure 5).

It is important to note that burning solid fuels for heating is a greater contributor to household air pollution in Bulgaria than the use of solid fuels for cooking. While some progress has begun to be made in this area as well, gaps remain. The International Energy Agency estimates that in 2020, 16% of heat generation in Bulgaria came from biofuels (IEA 2020). Following the adoption of the National Air Quality Improvement Program in 2019, legislation was enacted to control fuel quality standards for heating, whereby only fuels that meet the quality requirements can be distributed on the market (ECAC 2020).

IMPROVED AIR QUALITY, MORE DATA NEEDED

There are 57 stations measuring air quality in the country using regulatory-grade monitors; only 10 of these measure $PM_{2.5}$ of which 7 are located in the largest Bulgarian cities, and 27 stations monitor ozone (ECAC 2020). In 2019, a total of 48 stations were functional. There are seven stations in Sofia, five of which are within city limits. It is important to note that most air quality stations are located in urban centers, where households mostly use central/gas heating or electricity; thus, measurements in satellite villages where domestic heating is the dominant source of $PM_{2.5}$ are not available (e.g., outside of Sofia) (Dimitrova and Velizarova 2021).

> Data on air quality in Bulgaria remain limited, although there are some signs of progress in data availability.

Based on these data, in 2017 the Bulgarian Academy of Sciences (*https://www.bas.bg*) and the National Institute for Meteorology and Hydrology (NIMH *https://meteo.bg)* developed a publicly available 72-hour air quality forecast at the national level (*http://info.meteo.bg/cw2.1/*) and for Sofia City and Region (*http://info.meteo.bg/cw2.2/*), as

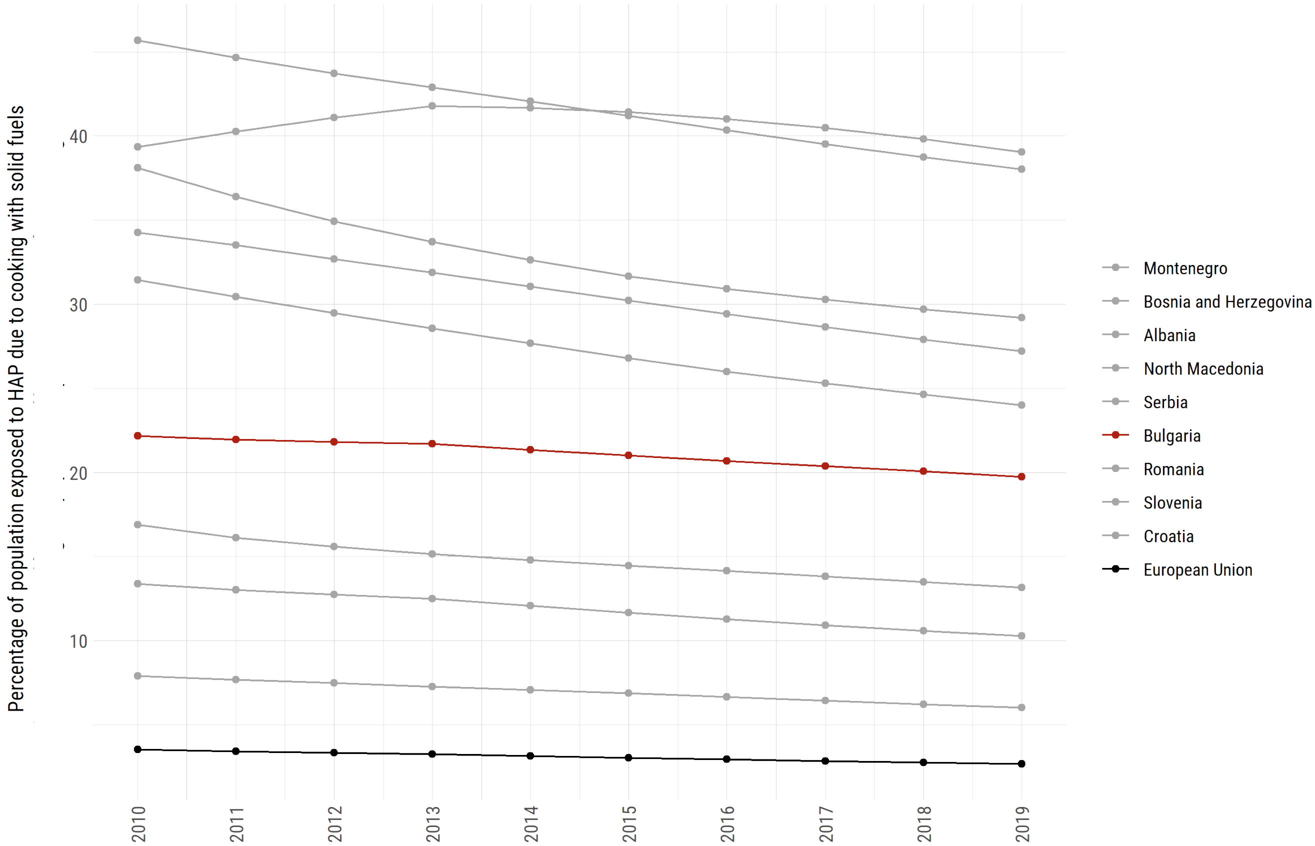


FIGURE 5 Trends in the percentage of population exposed to household air pollution (HAP) due to cooking with solid fuels in Bulgaria, Southeast Europe, and EU-28, 2010–2019 (HEI 2020). Visit *https://www.stateofglobalair.org/data* to explore data.

well as an early warning system for poor air quality in Sofia (*https://air.sofia.bg/*). A similar early warning system is currently being developed for Plovdiv at NIMH; however, the Municipality of Plovdiv does not yet have access to this system, and forecasts are not available to the public. Within the scope of the ongoing National Science Program "*Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters*" supported by the Ministry of Education and Science of Bulgaria, an update of the NIHM system is under development for Sofia, Plovdiv, and Varna, and will provide a 1-km resolution air quality forecast when ready.

In late 2019, Sofia municipality installed 22 geo-located air quality monitoring sensor stations through AIRTHINGS — funded by the Interreg Balkan-Mediterranean program and in partnership with four other cities (Thessaloniki, Nicosia, Tirana, and Skopje) —publishing the real-time data online (explore *here*). The program will install a total of 91 air quality stations across these cities. Also, outside Sofia, there are signs of progress. For example, prompted by citizens' complaints about poor air quality near the largest oil refinery in Bulgaria, Burgas was the first municipality to purchase a mobile air quality station in 2017.

In the last few years, citizen-driven air quality monitoring initiatives have played an important role in raising public awareness on poor air quality in Bulgaria. The largest of these is the Air Bulgaria platform, which deploys 900 $PM_{2.5}$ and PM_{10} sensors across Bulgaria. Data from the sensors are publicly and freely available (explore sensor data on map *here*, download data *here*). Other campaigns, including a program run by the Health and Environment Alliance (HEAL) to monitor indoor and outdoor air pollutants at 50 primary schools in six EU capitals, including Sofia, have targeted specific vulnerable populations or cities (HEAL 2019). Since 2019, NO_2 has been measured in Sofia by Air Bulgaria and Za Zemiata in cooperation with the Deutsche Umwelthilfe using passive samplers. Za Zemiata is continuing measurements throughout 2022 to assess the impact of a potential low-emission zone to be introduced and to underscore the importance of NO_2 reduction measures (Deutsche Umwelthilfe 2022).

Although there has been progress, there have been reports of regulatory-grade monitors malfunctioning frequently with long periods of time passing before they are fixed, resulting in substantial data gaps (ECAC 2020). Additionally, coverage of air quality monitoring, especially of $PM_{2.5}$, by the national air quality network is very sparse in cities despite the high density of populations in these areas. This sparsity of urban air quality data is similar across Eastern Europe, where the average distance to the nearest monitor is 690 km (Martin et al. 2019). Similarly, there are challenges in achieving sufficient quality assurance and quality control in sensor studies, thus exposure data must be interpreted with caution.

IMPACTS OF AIR POLLUTION ON HEALTH

Our health is strongly influenced by the air we breathe. Air pollution affects the young and the old, the rich and the poor, and people across the globe. However, the burden of disease associated with air pollution is not borne equally across regions and countries as variations reflect not only exposures, but also other social, economic, and demographic factors that affect the underlying health and vulnerability of populations to air pollution. Because socioeconomic development can be tied to both air pollution exposures and the availability of health care, changes in a country's level of development can also influence the burden of disease over time. Thus, lower-income households and communities are generally more vulnerable to the health effects from air pollution due to potentially greater exposure and to overall increased susceptibility given possible poor baseline health (e.g., exposure to other risk factors such as smoking), lack of access to health care, and limited ability to afford protective measures or improve housing quality. Additionally, the burden of disease attributable to air pollution does not fall evenly across age groups. Throughout the world, children and the elderly are those most acutely affected.

> Air pollution accounts for nearly 9% of total deaths in Bulgaria.

This section will explore the patterns and trends in the burden of disease in Bulgaria from total air pollution as well as the individual air pollutants that make up total air pollution in GBD estimates (i.e., $PM_{2.5}$, ozone, and household air pollution).

In Bulgaria, the number of total all-cause deaths as well as the all-cause death rate has increased over the last decade. The main causes of deaths in Bulgaria include ischemic heart disease; cerebrovascular disease (stroke and hypertensive heart disease); trachea, bronchus, and lung cancers; and several noncommunicable diseases that are also linked to air pollution. The three leading risk factors that account for the greatest disease burden are high blood pressure, dietary risk, and tobacco smoking (IHME 2020). Air pollution ranks as the seventh leading risk factor for deaths in Bulgaria in 2019 (Figure 6), and death rates linked to air pollution are among the highest in Europe.

EVIDENCE FROM BULGARIA

In the last several years, the body of evidence on health effects of air pollution has continued to grow in Bulgaria. Traditionally, respiratory health has been in the spotlight for research as the most apparent target of air pollution, although there is a growing recognition of health effects that extend beyond respiratory health. **Over 15 studies published since 2000 have focused on different pollutants including PM, PAHs, and gases (NO_2, SO_2), and have included analyses of health effects among children, adults, and patient populations.** National and local studies were identified through various literature databases; although we intended to include as many studies as possible, this is not an exhaustive literature review. Visit *here* for an interactive literature database featuring studies on air pollution and health in the region, including Bulgaria.

A recent study assessing short-term exposure to particulate air pollution ($PM_{2.5}$ and PM_{10}) in Sofia residents found increases in respiratory, cardiovascular, gastrointestinal, and neurological disease-related out-

Health Effects of Air Pollution

Understanding the burden of disease that air pollution places on society begins with scientific evidence for its effects on health. An extensive body of scientific evidence has been amassed over several decades, including studies from many countries of the world. Short-term exposures to air pollution can harm health; for example, pollution can trigger asthma symptoms and cause a local spike in hospitalizations or even deaths related to respiratory and cardiovascular diseases. There is broad scientific consensus that long-term exposures to air pollution contribute to increased risk of illness and death from chronic noncommunicable diseases, such as ischemic heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), stroke, and type 2 diabetes as well as lower-respiratory infections (e.g., pneumonia) especially in children under five. Exposure to $PM_{2.5}$ also puts mothers at risk of delivering babies too early and smaller than normal, and these babies are more susceptible to dying from a range of diseases or are considered to be at increased risk for diseases later in life. There is also emerging evidence on the role of air pollution in cognitive disorders, including dementia as well as impaired cognitive development in children. For example, air pollution was recently acknowledged as a modifiable risk factor by the Lancet Commission on dementia prevention, intervention, and care, and other effects (Livingston et al. 2020). Overall, the public disease burden from long-term exposures is much larger than that from short-term exposures. This large burden of disease reflects the substantial contribution that long-term exposures to air pollution make to chronic noncommunicable diseases and, more specifically, to some of the world's leading causes of death.

For a summary on health effects of air pollution, please refer to the *factsheet* and the resources listed at the end of the report. For data on health impacts of air pollution, please visit *https://www.stateofglobalair.org/health.*

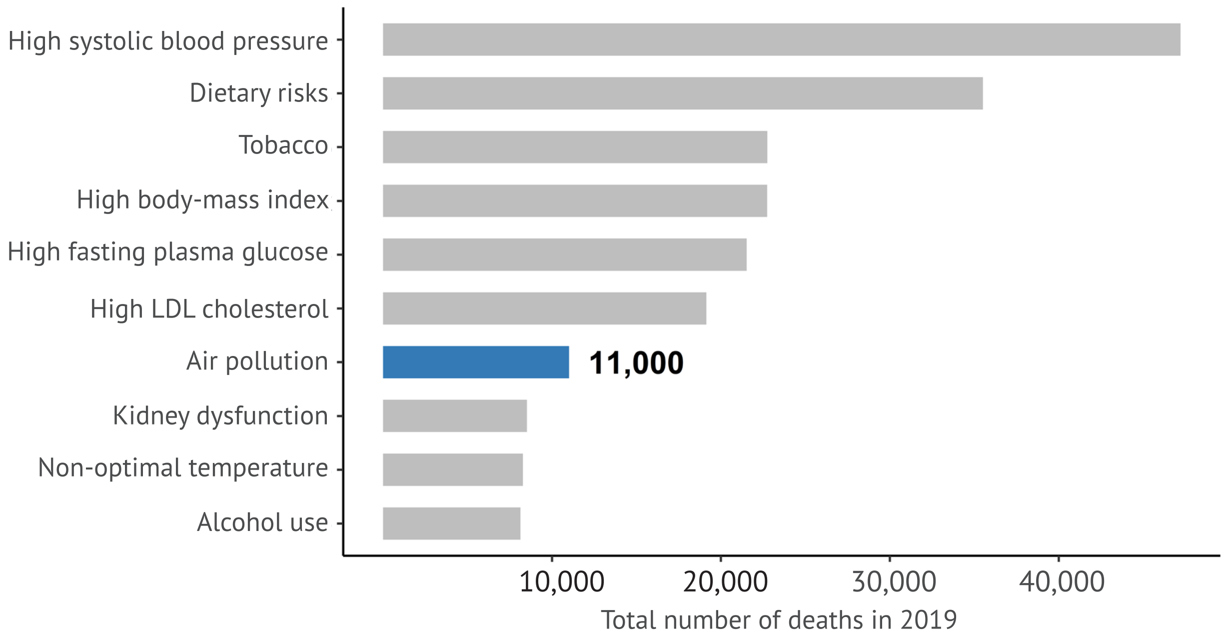


FIGURE 6 Ranking of risk factors by total deaths from all causes in Bulgaria in 2019 (IHME 2020).

patient and hospital emergency services, as well as a 10% increase in emergency ambulance contacts during peaks in air pollution that may persist with a lag of up to three days (Simidchiev et al. 2020).

Respiratory Health

Studies on effects of air pollution exposure among children have found associations with adverse health outcomes and air pollution (Turnovska et al. 2001, 2007, 2009). One study conducted in Plovdiv found that the combination of higher NO_2 and total suspended particulate matter (TSPM) at school and tobacco smoking had adverse effects on some respiratory and cardiovascular functions (Turnovska et al. 2007). Another study took advantage of the drastic decline in air pollution levels after the political reform in Bulgaria in 1989 and resulting decrease in industrial production. This natural experiment showed that children born after this shift, and thus exposed to considerably lower levels of TSPM and SO_2, had improved lung function compared with their counterparts who had high exposure to air pollution in their early life (Turnovska et al. 2009). A study on adolescents in Stara Zagora found that SO_2, NO_2, PM_{10}, and especially $PM_{2.5}$, were associated with decreased lung function (Prakova et al. 2014). A more recent study among COPD patients in the city of Pleven found a correlation between acute COPD aggravations and average PM_{10} in the previous six days (Krachunov et al. 2017). Higher PM_{10} exposures among COPD patients across 16 Bulgarian settlements were found to be associated with increased rates of exacerbation and longer hospital stays (Doneva et al. 2019).

Cardiovascular (Heart) Disease

A handful of studies also assessed the effect of air pollution on cardiometabolic (heart) disease. One study found daily concentrations of ozone and PM_{10} in the city of Varna in the period 2004–2005 to be moderately to highly correlated with hospital admissions for acute heart attack (Dimitrova et al. 2009). Cardiovascular effects of air pollution were also reported in the highly polluted Stara Zagora region. In another study, high correlations were reported between several pairs of air pollution indicators and cardiovascular disease (Platikanova et al. 2016). The role of air pollution on cardiometabolic outcomes was also investigated in a few studies that primarily looked at the health effects of traffic noise. One analysis in Plovdiv observed positive associations between type 2 diabetes and $PM_{2.5}$ and PAH (Dzhambov and Dimitrova 2016). Another study reported an increased association between road traffic noise and adiposity in patients with cardiovascular disease (Dzhambov et al. 2017).

Immunity and Genotoxicity (cancer precursors)

In another large study, Bulgaria partnered with the Czech Republic and Slovakia in the international EXPAH project, which aimed to explore mechanisms of air pollution carcinogenicity (Taioli et al. 2007). In participants exposed to high levels of PAHs, investigators found evidence of oxidative stress, which can lead to cell and tissue damage, and genotoxicity, which may lead to cancer. Notably, PAH levels were several-fold higher in Bulgarian participants living in Sofia than in the two non-Bulgarian cities (Taioli et al. 2007; Rossner et al. 2007). In addition, another study observed increased associations with air pollution and genotoxicity in Sofia during the winter months (Gábelová et al. 2004).

Adverse changes in the immune system, known to underlie a number of chronic diseases, have been studied in children and youth. In 2001, one study found no differences in immunological biomarkers measured in schoolchildren living in the city of Dimitrovgrad (highly industrialized) and the town of Nova Mahala (lacking major sources of air pollution) (Turnovska et al. 2001). More recently, another team compared biomarkers of systemic inflammation in adolescents living in three cities in southern Bulgaria and found alterations leading to immunity suppression responses in participants living in the city of Stara Zagora, one of the most polluted regions in the country owing to a nearby coal power plant (Dobreva et al. 2015).

HEALTH IMPACT ASSESSMENTS

In addition to the health and air pollution research summarized above, some additional related evidence comes from health impact assessments. On a large Europe-wide scale, Barcelona Institute for Global Health (ISGlobal) assessed premature mortality due to air pollution in nearly 1,000 cities across the 31 EU member states and found that Sofia, Bulgaria, ranked among the top 100 cities for highest number of premature deaths from air pollution (Khomenko et al. 2021). A regional health impact study looking at excess mortality from coal-fired power plant emissions noted that Bulgaria and Croatia were located downwind from major EU coal-burning emitters and found significant resulting excess death rates (with excess defined as >100 deaths per 100,000 inhabitants per year) in Bulgaria (142 deaths per 100,000 people; 95% CI: 126.2–157.9) (Kushta et al. 2021).

BURDEN OF DISEASE FROM AIR POLLUTION IN BULGARIA

In 2019, 11,000 deaths (95% UI: 8,406–14,043) were linked to exposure to air pollution, representing nearly 9% percent of total deaths in Bulgaria; of these, a majority were linked to exposure to outdoor $PM_{2.5}$ (Figure 7). Overall, while both the total number of deaths attributable to air pollution and the death rate (i.e., deaths/100,000 people) have declined in the last decade, a rate of 159 deaths per 100,000 people in Bulgaria represents the highest in the Southeast European region, nearly twice the global death rate attributed to air pollution (86.2, 95% UI: 76.3–96.8). For comparison, this rate is approximately half the death rate from smoking in Bulgaria (328 deaths/100,000 people, 95% UI: 262–404).

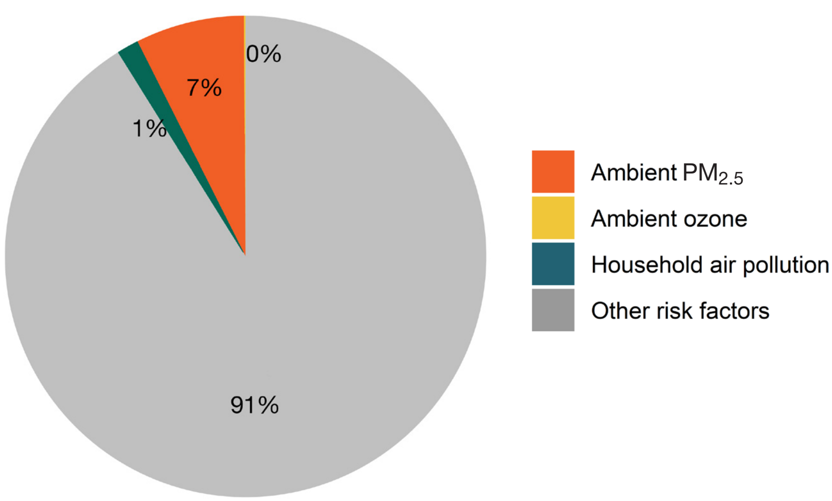


FIGURE 7 Percentage of deaths linked to individual air pollutants in Bulgaria in 2019.

Fine Particulate Matter ($PM_{2.5}$)

In 2019, 9,000 (95% UI: 7,041–11,358) deaths were attributable to ambient $PM_{2.5}$. In the last decade, the overall number of deaths in Bulgaria attributed to $PM_{2.5}$ decreased by approximately 14%.

Despite slow progress, the disease burden of ambient $PM_{2.5}$ remains high.

Similarly, while the average age-standardized death rate attributable to $PM_{2.5}$ in Bulgaria decreased from 142 deaths/100,00 people (95% UI 119.8–163.1) in 2010 to 131 deaths/100,000 people in 2019 (Figure 8), this rate is more than twice the respective global death rate (53.5 deaths/100,000; 95% UI 44.6–62.0) and more than five times that of Western Europe (26.2 deaths/100,000; 95% UI 19.4–33.5 (Figure 9).

Ozone

In Bulgaria, 154 deaths (95% UI: 64–265) were linked to exposure to ozone in 2019. Similar to the downward trend of total number of deaths attributable to ozone in the last decade, the ozone-related death rate in Bulgaria declined by ~8%, from 2.7 (1.2–4.5) in 2010 to 2.2 deaths/100,000 people (0.9–3.8) in 2019.

The average number of ozone-related deaths in Bulgaria decreased between 2010 to 2019.

Most of the ozone-related deaths occurred in people 60 years and older (Figure 10). COPD is the only health outcome that is considered for ozone in GBD, and 5% of the total COPD deaths in Bulgaria are linked to ozone exposure.

Household Air Pollution – Cooking

In Bulgaria in 2019, use of solid fuels for cooking resulted in 1800 deaths (95% UI: 549–4,178), representing a decrease by approximately 24% since 2010. This decline in the last decade is in line with the related decrease in deaths attributed to household air pollution in the region (by 30%). Similarly, household air pollution–attributable age-standardized death rates decreased in from 31.9 deaths/100,000 people (95% UI: 11.2–67.6) in 2010 to 26.1 deaths/100,000 people (95% UI: 7.9–60.3) in 2019. This follows the same trend as the rest of the Southeast Europe region (Figure 8) (see *Trends in Air Quality and Health in Southeast Europe: A State of Global Air Special Report* for details).

Good news: The burden of disease from household air pollution has decreased steadily over the past decade.

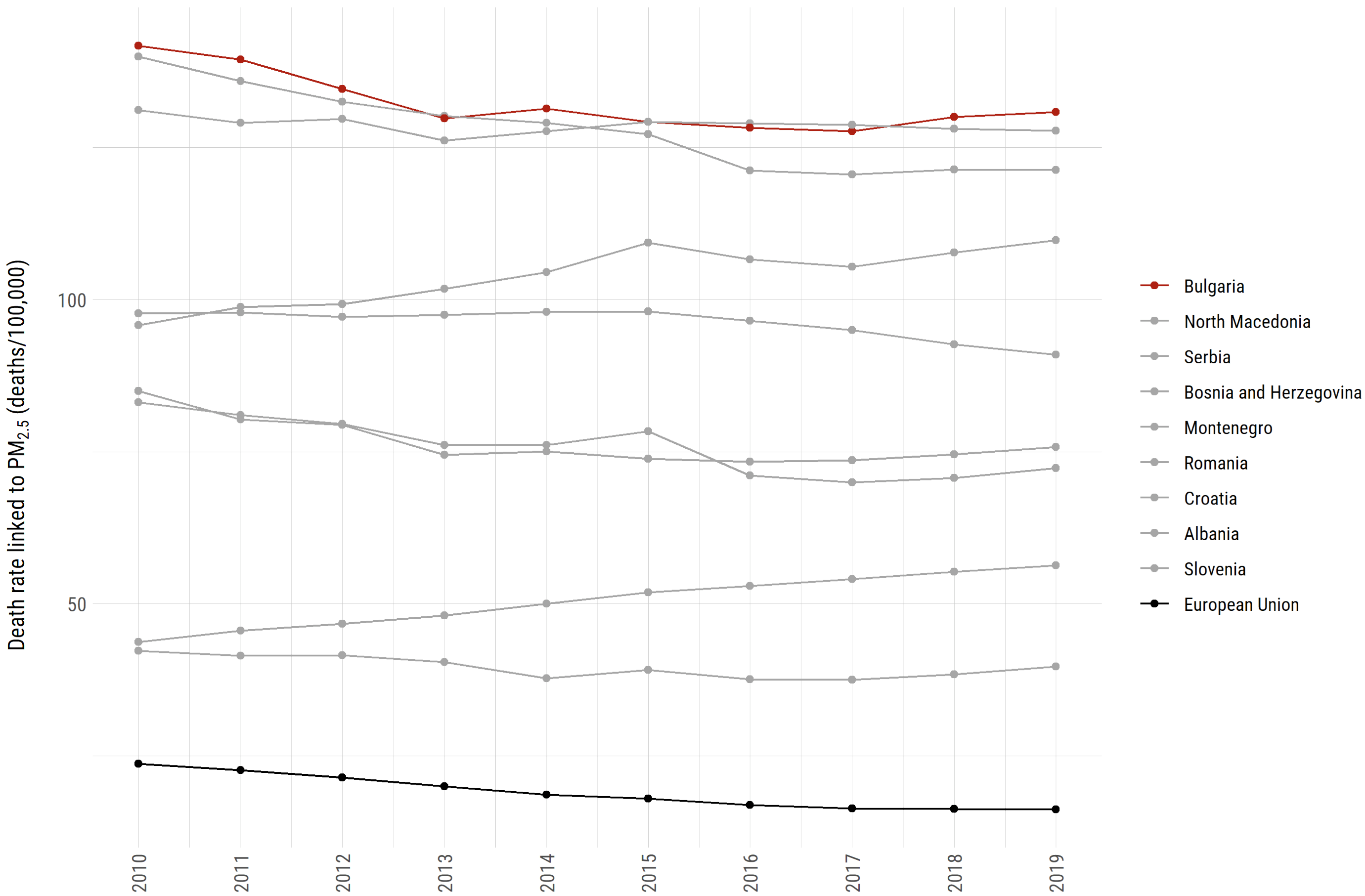


FIGURE 8 Trends in $PM_{2.5}$ death rate in Bulgaria, Southeast Europe, and EU-28, 2010–2019 (HEI 2020). Visit *https://www.stateofglobalair.org/data* to explore data.

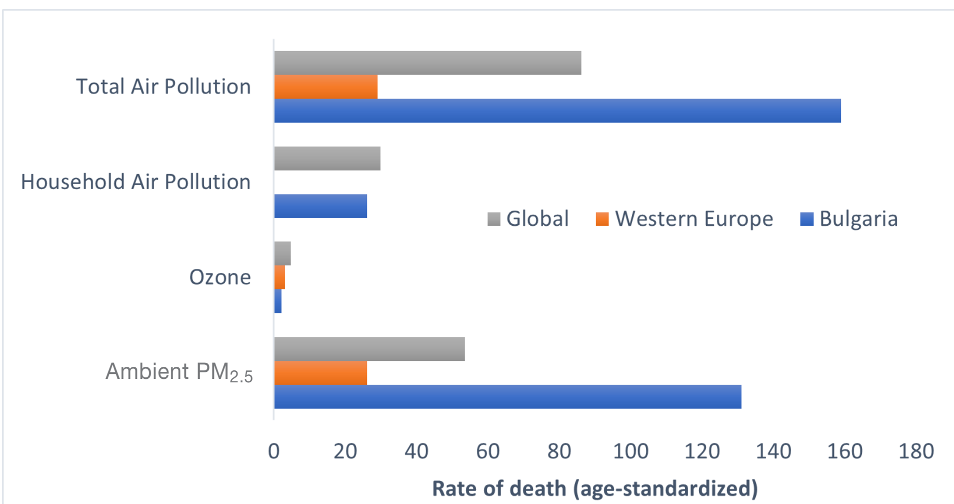


FIGURE 9 The death rate (age-standardized) (deaths/100,000 people) linked to total air pollution, $PM_{2.5}$, ozone, and household air pollution from solid fuels in Bulgaria in 2019.

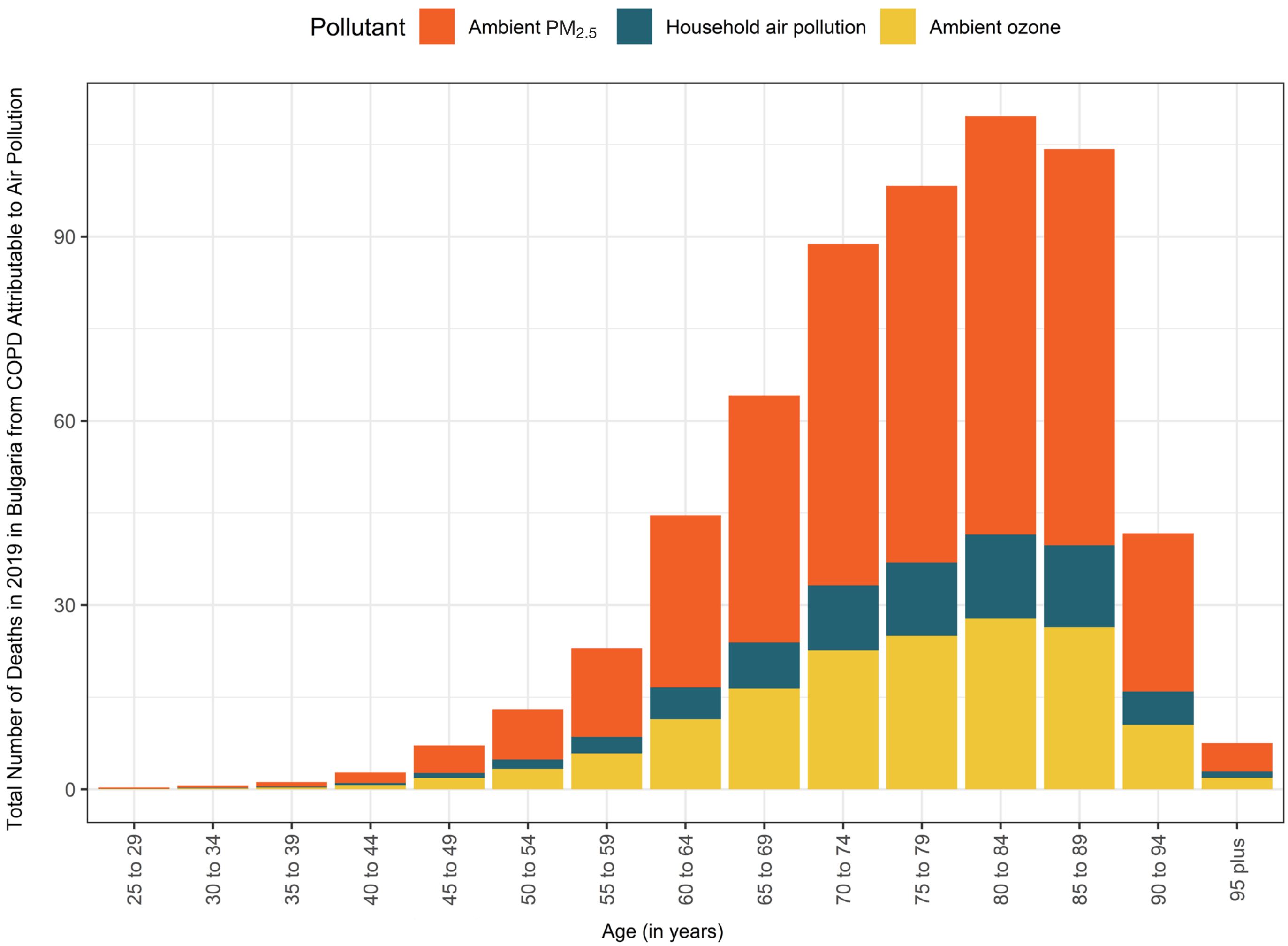


FIGURE 10 Distribution of COPD-related deaths in 2019 in Bulgaria linked to air pollution by age [25+ years].

GREATEST IMPACT ON THE YOUNGEST AND THE OLDEST

In Bulgaria, noncommunicable diseases rank among the most frequent causes of death with cardiovascular disease, diabetes, and chronic respiratory diseases and infections ranking among the top ten causes of death; many of the same diseases are also linked with exposure to air pollution.

> Air pollution makes a significant contribution to the disease burden including from heart and chronic lung disease and diabetes.

Specifically, 20% of all COPD-related deaths were attributed to air pollution (Figure 11), with the largest fractions of those deaths attributable to $PM_{2.5}$ (13%) and ozone (5%) (explore *here*). Other health outcomes for which air pollution presents a key risk factor in Bulgaria are type 2 diabetes, lung cancer, stroke, and heart disease.

> 68% of all air pollution–related deaths in Bulgaria were in people over the age of 70.

In Bulgaria, and as seen across Southeast Europe, the largest number of air pollution–related deaths occur in people aged 70 or older; a majority of these (82%) are related to exposure to ambient $PM_{2.5}$ (Figure 12). This peak reflects the contribution of air pollution to major noncommunicable diseases that develop over time — ischemic heart disease, stroke, COPD, lung cancer, and type 2 diabetes. At the same time, 6% of the deaths among newborns were linked to air pollution.

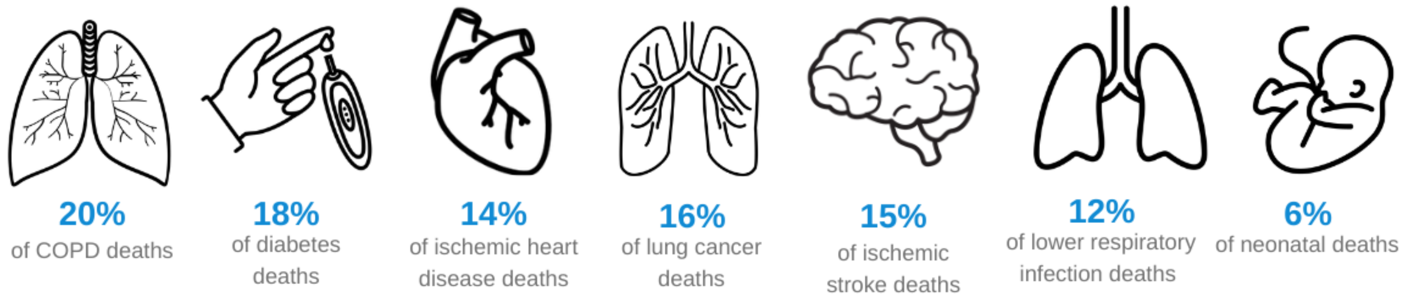


FIGURE 11 Percentage of deaths (by cause) linked to air pollution in Bulgaria in 2019.

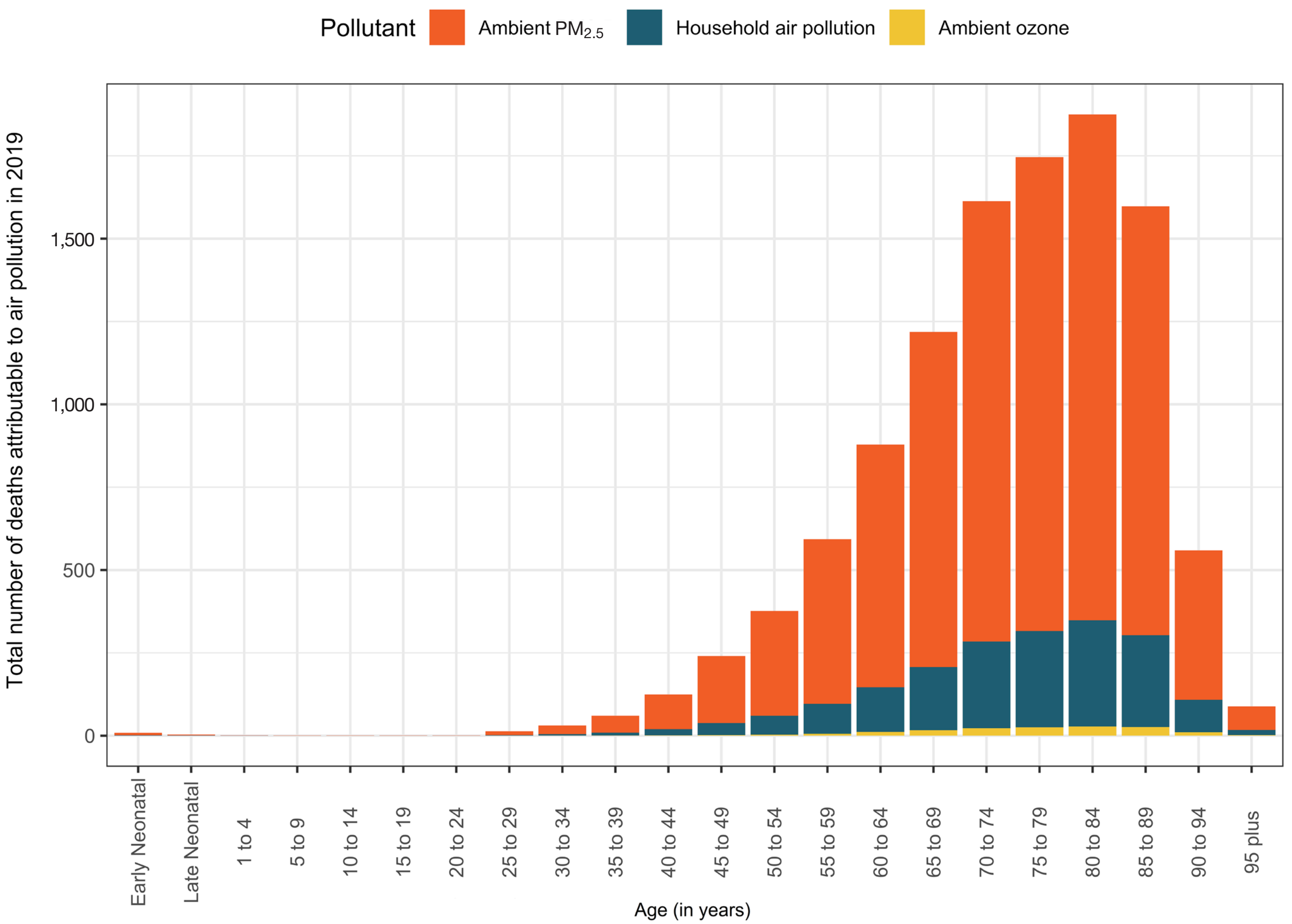


FIGURE 12 Distribution of deaths in 2019 in Bulgaria linked to air pollution by age (years, except early neonatal [0 to 6 days] and late neonatal [7 to 27 days]) (HEI 2020).

BURDEN OF DISEASE RELATED TO MAJOR SOURCES OF AIR POLLUTION

Energy generation and use, including the use of fossil fuels (coal, oil, and natural gas) and solid biofuels, is the single largest contributor to outdoor $PM_{2.5}$ and the related disease burden in Bulgaria (Figure 13). In fact, across all sectors, coal use accounted for 18.5% of all ambient $PM_{2.5}$ in 2019. Coal remains a key fuel for energy production and, in the absence of access to clean energy in homes, people rely on using coal and other solid fuels to heat homes, especially during the winter season. A large proportion (41%) of the country's population is considered energy-poor[4], the highest proportion in the EU. Use of inefficient and polluting energy sources for residential heating has also been identified as a key contributor to the country's disease burden and the national $PM_{2.5}$ and PM_{10} emissions in Bulgaria.[5]

Residential combustion is the single largest contributor to ambient $PM_{2.5}$ levels and the associated disease burden (17.6%, or 1,645 deaths), followed by energy production (17%, or 1,589 deaths). According to these estimates, a majority (88%) of the fuel burned at homes is solid biofuel, while only 10% is coal (Figure 14). Other major contributing sectors include windblown dust (14%, or 1,309 deaths) and agriculture (13%, or 1,187 deaths) (Figure 14) (McDuffie et al. 2021). Agriculture was found to be an important contributor in many European countries. In fact, the sector is increasingly coming into focus in the EU policy discourse, in part due to an increasing understanding of the role of ammonia emissions in poor air quality and the need to reduce greenhouse gas emissions. Ammonia can contribute to secondary particle formation, which contributes to formation of PM in the atmosphere.

> Use of fossil fuels (i.e., coal, oil, and natural gas) is linked to 30.4% of the total disease burden related to $PM_{2.5}$ in Bulgaria.

It is important to note that source contributions often vary across national and urban scales. For example, although transportation did not emerge as a leading source of disease burden at the national level (7%), at the urban/city scale, traffic can be a large contributor to ambient $PM_{2.5}$. Across Bulgarian cities, residential, transportation, and energy sources were estimated to make the largest contributions to ambient $PM_{2.5}$ and PM_{10} levels (Belis et al. 2019; Perrone et al. 2018), in line with estimates presented here. The problem is also compounded by the old diesel vehicles imported from Western Europe, most of which emit air pollutants at a much higher rate compared to new vehicles (UNEP 2021). Other studies have noted that while energy production and transportation are more important sources in Bulgarian cities, agriculture is the leading source of air pollution in rural areas (Tsanova et al. 2021). Overall, targeted source-apportionment research, especially assessing sources of $PM_{2.5}$ at city and provincial levels, is needed.

[4] *https://library.oapen.org/bitstream/handle/20.500.12657/41750/2019_Book_EnergyDemandChallengesInEurope.pdf?sequence=1#476184_1_En_11_Chapter.indd%3AC00011CR5%3A32.*

[5] *https://www.ceip.at/.*

How did we identify major sources of air pollution?

We report major sources of air pollution at national levels for countries in Southeast Europe based on the data from the GBD MAPS Global study (McDuffie et al. 2021). As sources of air pollution often differ between rural and urban areas, we also included some studies conducted in major cities in the region to provide additional insights on local sources. The GBD MAPS Global study provided the first contemporary and comprehensive global evaluation of major sources of $PM_{2.5}$ by fuel type and by sector in more than 200 countries using a consistent methodology and global emissions inventories. It utilized updated Community Emissions Data System emissions inventories, satellite data, ground-monitoring data, and advanced air-quality modeling (GEOS-Chem model) to estimate the $PM_{2.5}$ exposures from 16 sectors and 4 different fuel types (McDuffie et al. 2021). Unlike regulatory emissions data, the GBD MAPS Global study considered both anthropogenic sources (e.g., residential use, industry, and transportation) and natural sources (e.g., windblown dust, open fires, and volcanoes). It also estimated deaths linked to different sources of $PM_{2.5}$ using GBD methodologies. More details about this study can be found *here*.

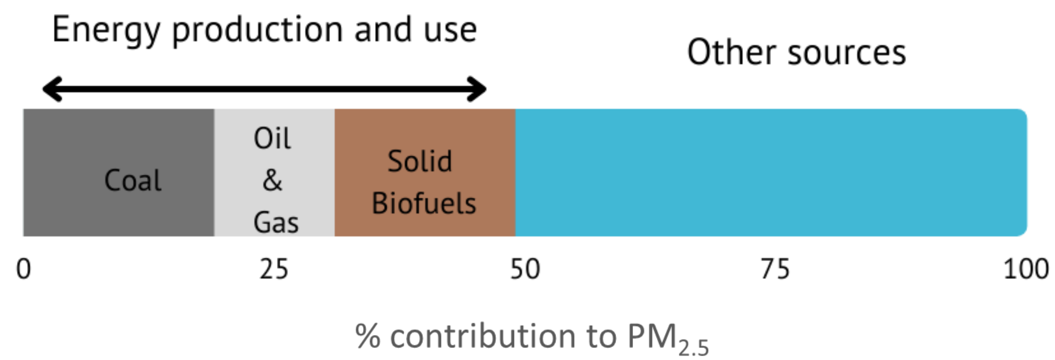


FIGURE 13 Contribution to $PM_{2.5}$ concentrations by fuel type in Bulgaria in 2019 (Source: McDuffie et al. 2021).

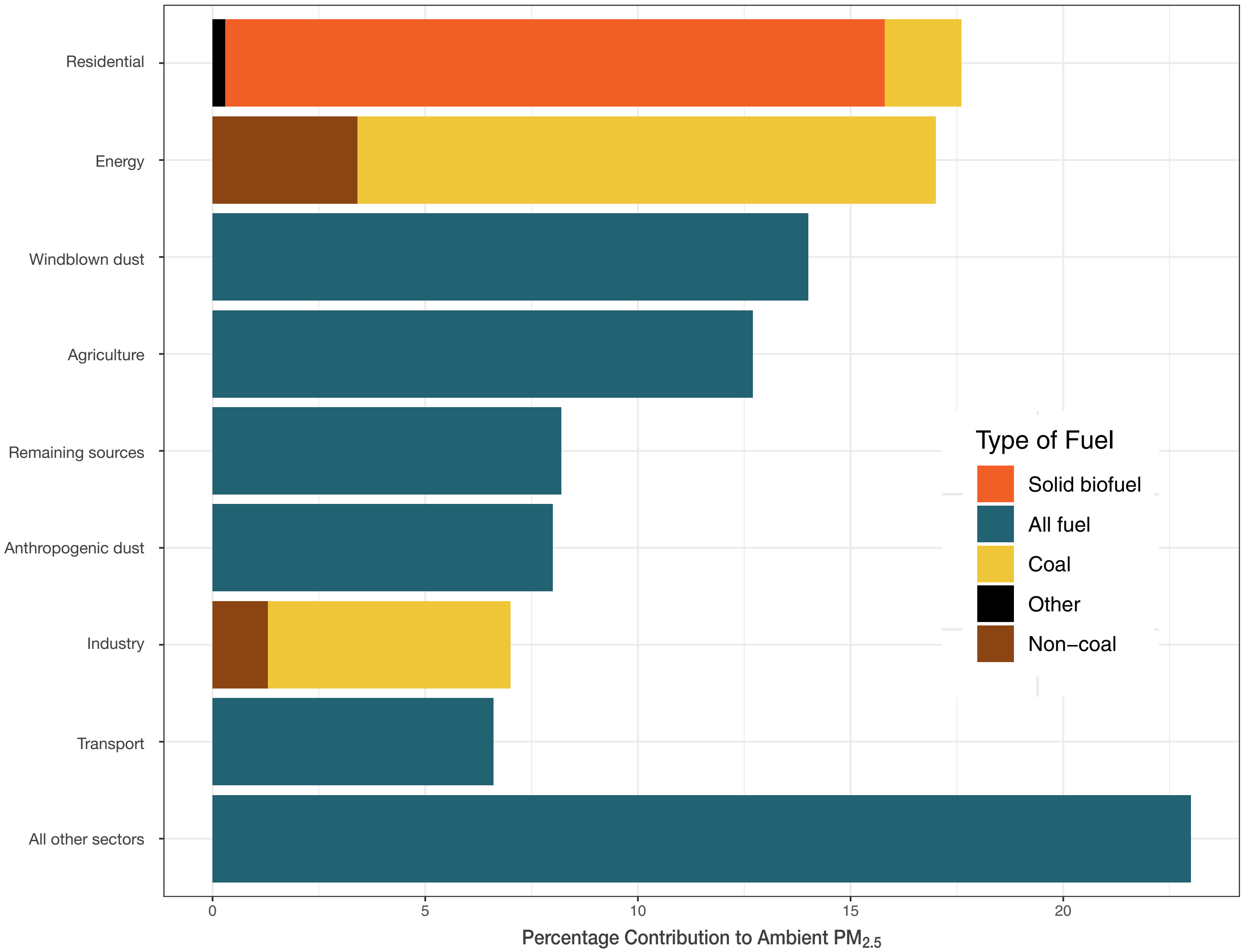


FIGURE 14 Contribution of $PM_{2.5}$ concentrations by sector in Bulgaria in 2019 (McDuffie et al. 2021).

CONCLUSIONS

Although Bulgaria has made significant progress on reducing exposure to air pollution in the last decade, air pollution remains a leading risk factor for death and disability, and death rates linked to air pollution are among the highest in Europe. Bulgaria is one of the poorest countries in the EU, and its energy poverty and access to clean energy remain key issues. A significant proportion of the country's population cannot afford to heat their homes or have limited access to district heating. Energy production continues to rely on old, inefficient coal-fired power plants. As a result, use of fossil fuels, including coal, oil, and natural gas, as well as the use of solid biofuels in households are the dominant sources of ambient $PM_{2.5}$ — accounting for nearly half of the total disease burden related to $PM_{2.5}$ in Bulgaria. Substantial health benefits can be expected once the pollution is controlled, reduced, or eliminated.

In recent years, there has been an increase in public awareness and a growing momentum for action, spurred by the availability of data, in part due to the European Court of Justice ruling, and by visible air pollution episodes in winter. This awareness has been bolstered by an increase in accessible air pollution data from citizen–science monitoring networks, which in turn allow the public to demand improved air quality and related policy action.

To achieve clean air, regional and national collaborations are necessary. It is important to not only expand and improve access to air quality data and support health studies, but also support collaborations among researchers, physicians, and civil society experts. Just as the COVID-19 crisis has demonstrated the need for multiple strategies to manage the pandemic, solutions to air pollution will require multifaceted ongoing efforts to bring attention to its health threats, to identify the policy changes necessary to control it, and to monitor progress over time.

More research investigating the association between air pollution and health is essential both on the national and local levels. Fortunately, Bulgarian researchers have expanded the scope of their research studies beyond classic respiratory health outcomes of air pollution and have begun to look into effects on cardiovascular, metabolic, and immunological health outcomes. Additionally, both short- and long-term effects of air pollution have been investigated, and a handful of studies conducted used more advanced exposure assessment techniques. Lastly, there is increasing interest in the effects of air pollution in vulnerable population groups, such as children, the elderly, and patients with chronic conditions.

Existing evidence on air pollution emission sources and related disease burden indicates that implementing emission reduction strategies on the sectors with the highest contributions to ambient air pollution and health impact in Bulgaria — that is, residential fuel combustion, energy production and agriculture — would greatly improve air quality and related health, economic, and societal benefits.

iStock.com/Stanislava Karagyozova

Bobov Dol Thermal Power Station near the town of Bobov Dol, Kyustendil Province, western Bulgaria

ABBREVIATIONS

AFCID	anthropogenic fugitive, combustion, and industrial dust
COPD	chronic obstructive pulmonary disease
COVID-19	infectious disease caused by the novel coronavirus SARS-CoV2
ECAC	European Clean Air Centre
EEA	European Environment Agency
EU	European Union
GBD	Global Burden of Disease
HEI	Health Effects Institute
IHME	Institute for Health Metrics and Evaluation
ISGlobal	Barcelona Institute for Global Health
NIMH	National Institute for Meteorology and Hydrology
NO_2	nitrogen dioxide
NO_x	nitrogen oxide
OECD	Organisation for Economic Co-operation and Development
PAH	polycyclic aromatic hydrocarbon
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 µm in aerodynamic diameter
PM_{10}	particulate matter ≤10 µm in aerodynamic diameter
SO_2	sulfur dioxide
SoGA	State of Global Air
TSPM	total suspended particulate matter
UI	uncertainty interval
VOC	volatile organic compound
WHO	World Health Organization

KEY RESOURCES

Global Burden of Disease 2019 Methods

These resources provide background details on the latest GBD methods used to estimate $PM_{2.5}$, ozone, and household air pollution exposures and the deaths reported here.

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Explore and download additional information and data on mortality and disease burden for air pollution, as well as other risk factors, at the IHME GBD Compare site at https://vizhub.healthdata.org/gbd-compare/.

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