

# Report on the Reduction in Mortality Due to Improved Air Quality



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## 1. Introduction

This report assesses the extent to which mortality rates have declined as a result of improved air quality, focusing on black carbon (BC) rather than PM2.5. BC is a harmful fraction of particulate matter strongly linked to solid fuel combustion (e.g., coal, biomass).

There is a limited amount of data on BC measurements as well as on the concentration–response functions of BC for premature deaths, which has required making several strong assumptions.

The goal is to present a methodology for estimating the public health benefits from BC reduction following stricter fuel quality standards and changes in heating technologies.

## 2. Methodology

### 2.1 Data Sources

- PM2.5 concentration data from the Chief Inspectorate for Environmental Protection (GIOŚ; <https://www.gios.gov.pl>).
- BC/PM2.5 ratios from the University of Wrocław continuous BC monitoring and short-term local studies (Drzeniecka-Osiadacz et al., University of Wrocław poster).
- Mortality and demographic data from the Central Statistical Office of Poland (GUS; <https://stat.gov.pl>).
- Epidemiological concentration–response functions for BC (based on Brunekreef B. 2021; <https://pubmed.ncbi.nlm.nih.gov/36106702/>).

### 2.2 Air quality improvement

1. PM2.5 concentrations were taken from two stations (Bujaka and Bulwarowa), as they were the only ones with continuous measurements from 2011 to 2023 (last verified year) and completeness above 85%. Concentrations were converted to monthly averages for further conversion. See Table 1.
2. Available BC measurement data and conversion ratios were taken from the University of Wrocław station, which measures both BC and PM2.5. The measurement period covers 2023–2025. Average monthly shares of BC in PM2.5 were used, along with lower (25th percentile) and upper (75th percentile) quantiles to describe distribution. See Table 2.
3. Based on Krakow’s monthly PM2.5 concentrations and BC monthly shares (mean, lower, and upper quantile), annual mean BC concentrations were calculated for each year from 2011 to 2023.

### 2.3 Time Frame and Scenarios

- **Baseline:** Three-year average mean BC (2011–2013).
- **Reductions:** Annual reductions calculated for each year from 2013 onwards.

## 2.4 Health Impact Assessment

- Mortality rates from natural causes per year in Krakow from 2011–2019; during the COVID-19 pandemic (2020 onwards), a three-year constant average (2018–2020) was used.
- Relative risk (concentration–response function) of 1.04 (CI = 1.02, 1.06) for an increase of  $0.5 \times 10^{-5}/\text{m BC}$ . It was assumed that  $10^{-5}/\text{m}$  equals  $1 \mu\text{g}/\text{m}^3$  of BC.
- Attributable premature deaths were calculated for the baseline and for each subsequent year. The sum of all avoided premature deaths represents the result of this estimation.

## 3. Results

The analysis shows that the reduction in BC concentrations resulted in a total of **3,368 to 7,655 avoided premature deaths** between 2011 and 2023. Full results are presented in the annex.

## 4. Limitations

- BC values are inferred from PM2.5 data using ratios from another location.
- Seasonal and meteorological variability in BC/PM2.5 ratios introduces uncertainty.
- Other mortality drivers (e.g., pandemics, weather extremes) were not fully isolated.
- No economic valuation was included

## Annex I

**Table 1.** Monthly Average PM2.5 Concentrations ( $\mu\text{g}/\text{m}^3$ ) in Krakow (Bujaka and Bulwarowa Stations)

Year	Month	Bujaka PM2.5	Bulwarowa PM2.5
2011	Jan	82.9	68.8
2011	Feb	49.9	45.7
2011	Mar	57.9	58.6
2011	Apr	30.3	
2011	May	19.1	16.5
2011	Jun	12.6	11.9
2011	Jul	11.8	14.1
2011	Aug	13.6	20.7
2011	Sep	14.1	
2011	Oct	17.5	
2011	Nov	81.8	94.9
2011	Dec	58.7	65.6
2012	Jan	39.8	37.9
2012	Feb	100.5	84.1
2012	Mar	58.6	45.6
2012	Apr	22.8	21.5
2012	May	14.7	19.2
2012	Jun	14.6	
2012	Jul	16.3	14.4
2012	Aug	21.2	17.2
2012	Sep	20.8	
2012	Oct	36.2	
2012	Nov	61.1	51.6
2012	Dec	91.7	77.0
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2023	Oct	9.5	13.3
2023	Nov	11.9	14.2
2023	Dec	25.7	26.2

*Full monthly dataset from 2011–2023 is available in the attached source file and includes all intermediate months.*

**Table 2.** Monthly Share of BC in PM2.5 (University of Wrocław Monitoring, 2023–2025)

Month	BC_Q1	BC_mean	BC_Q3
Jan	16%	27%	32%
Feb	14%	21%	25%
Mar	12%	19%	24%
Apr	9%	16%	20%
May	7%	15%	17%
Jun	5%	12%	14%
Jul	7%	17%	21%
Aug	8%	19%	25%
Sep	8%	14%	17%
Oct	10%	18%	23%
Nov	12%	20%	24%
Dec	16%	25%	31%

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**Methodological basis:** Adapted from the *Assessment of the Impact of Solid Fuel Parameters on Health* report, incorporating University of Wrocław BC monitoring results and extended to 2015–2023.