Appendix

MATERIALS AND METHODS

The analysis on health impacts and cost for this report was carried out by the Centre for Research on Energy and Clean Air (CREA). It follows the most common approach for studying the health impacts of air pollutant emissions, the "impact pathway" approach, which follows air pollution from emissions from the studied sources, to the dispersion and chemical transformation of emissions, to resulting pollution levels in different locations, to population exposure, resulting increase in health impacts and finally to the total health impacts on the population-level.

AIR POLLUTANT EMISSIONS

Data on air pollutant emissions for Polish thermal power plants for the year 2019 was taken from the EEA Industrial Reporting Database, where the Polish government reports official annual plant-level emissions data.

The main fuel was detected for each combustion plant based on fuel input data, with the most used fuel designated as the main fuel. Power plants were detected initially based on the "main activity" reported for each plant, and secondarily based on the name of the facility, when the main activity information was missing, with words such as "elektrociepłownia" (for CHP plant) and "ZEC" (for Zakład Energetyki Cieplnej) and "energetyka" used to detect power plants. These designations were then checked manually.

As all combustion plants are required to comply with the Large Combustion Plant Best Available Technology Reference document (LCP BREF) emission values by 2023, future emissions scenarios have to take into account the associated reductions in emissions.

We estimated the current average flue gas concentrations (FGC) of pollutants using the fuel consumption data in the IRD and fuel-specific average factors for specific flue gas volume per heat input (SFGV, in Nm3/GJ) for hard coal, lignite, gaseous fuels, biomass and heating oil from Graham et al (2012).

$$FGC_{P,S} = \frac{E_{P,S}}{\sum_{F} (SFGV_{F} \ x \ H_{P,F})},$$

where subscripts P, S and F refer to a plant, a substance and a fuel type,
E is the emission mass rate (t/year), and H is the heat input of a fuel (GJ/year)

We then projected the emissions under full compliance with the LCP BREF (BAT_emissions) using the formula:

$$BAT\_emissions = E_{P,S} \ x \ \frac{BATAEL_{P,S}}{FGC_{P,S}},$$

where BATAEL refers to the upper BAT-aligned emission level
specified in the LCP BREF for a specific fuel, substance and plant capacity.

For new, planned coal- and gas-fired power plants, emissions were projected based on the LCP BREF emissions limits, power generating capacity and thermal efficiency from GCPT and GGPT, assuming the current average utilization by plant type (gas or coal-fired; CHP or conventional).

$$E_{P,S} = \frac{CAP_P}{EFF_P} \ x \ SFGV_F \ x \ CF_F \ x \ BATAEL_{P'}$$

where CAP is the net electrical capacity of the plant, EFF is the net thermal efficiency (fuel-to-power efficiency), and CF is the capacity factor

The Polish Energy Plan (PEP 2040) specifies power generation and capacity by fuel, plant type (CHP or conventional) and year out to 2040. To project emissions under the plan, we arranged the power plants in each category into an order of retirement, based on announced years of retirement and commissioning years, retiring those power plants first whose announced retirement date has passed, and then the oldest ones amont the others. We then adjusted the operating hours of the remaining power plants so that total generation matched the generation projected in PEP. Emissions were adjusted assuming that they are directly proportional to power generation.

We projected emissions over time for three different phase-out scenarios:

- **2030 clean power:** all fossil fuel-fired power generation phased out by the end of 2030. Power generation from biomass and biogas follows the PEP until 2040 and is then frozen at the 2040 level
- **2035 clean power:** same as above but all fossil fuels phased out by the end of 2035
- **2049 coal phase-out:** all fuels follow the PEP until 2040, and then coal is phased out by the end of 2049 and other fuels are frozen at 2040 level.

In the case of the 2030 phase-out, we assumed that a 10% reduction in fossil fuel power generation from the levels in the PEP would be achieved in 2025, increasing linearly to 80% in 2030 and 100% in 2031. In the 2035 phase-out scenario, the phase-out was assumed to proceed linearly to 80% by 2035, starting from 2025, and 100% in 2036. In the 2049 coal phase-out, the phase-out was assumed to proceed linearly, starting from 2040, reaching 80% in 2049 and 100% in 2050.

ATMOSPHERIC MODELING

The air quality and health impacts of the different scenarios were projected using the atmospheric chemical-transport model for the European region developed under the European Monitoring Programme Meteorological Synthesizing Centre - West (EMEP MSC-W) of the Convention on Long-Range Transboundary Air Pollution (CLRTAP). Model code (version rv4.36, based on the version used in EMEP status reporting for the year 2020) and the required input datasets were provided by EMEP MSC-W and the Norwegian Meteorological Institute. These inputs include the baseline emissions inventory for 2015, 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).

The baseline emission inventory for the model, including emissions of all sectors in all countries at a resolution of 0.1x0.1 degrees, was also developed under EMEP. We updated the inventory to the latest emissions data for thermal power plants, replacing the electricity sector emissions values in the grid cells containing thermal power plants with the emissions data for those power plants.

We modeled the air quality impacts of Polish thermal power plants under four different scenarios: 2019 emissions, 2023 emissions under full BREF compliance, as well as 2035 and 2050 emissions under PEP 2040 generation and capacity projections, combined with our projected plant retirements. For each of these scenarios, the air quality results were compared with the results from a "zero-out" model run in which the emissions of Polish thermal power plants were entirely removed from the model. The difference in concentrations between the scenario and zero-out simulations is the estimated impact of thermal power plants to air pollutant concentrations.

The air quality impacts for the other scenarios were derived from these modeling results by scaling down the pollutant concentrations by the changes in emissions compared to the modeled PEP 2040 scenario.

HEALTH IMPACT ASSESSMENT

The health impacts of the changes in pollutant concentrations were evaluated by assessing the resulting population exposure, based on the gridded population data for 2020 from CIESIN (2017), and then applying the health impact assessment recommendations of WHO HRAPIE (2013) as implemented in Huescher et al (2017). We updated the concentration-response function for mortality related to long-term exposure to NO2 based on the recent meta-analyses of available epidemiological studies carried out to inform the update of the World Health Organization air quality guidelines by Huangfu & Atkinson (2020).

Baseline mortality for different causes and age groups and different countries were obtained from Global Burden of Disease results (IHME 2020), and the baseline incidence of other health outcomes from the same sources as in Huescher et al (2017).

It is important to note that while most of the health impacts attributed to gas power plant emissions in our results are related to PM2.5, the main contributor to these emissions are the emissions of NOx, NH3 and VOCs through their effects on the formation of particulate pollution in the atmosphere.

Future health impacts projects account for projected population growth on the national level, and for mortality impacts, using projected changes in age-specific death rates based on the UN DESA (2019) medium variant. Use of age-specific death rates captures the impact of expected improvements in population health status and health services, which results in lower mortality for children, while increasing the susceptibility of the adult population to non-communicable diseases associated with air pollution.

Table A1.

Risk ratios (RRs) used for the health impact assessment, for a 10µg/m3 change in annual average pollutant concentration

POLLUTANT	EFFECT	RR: CENTRAL	RR: LOW	RR: HIGH	REFERENCE
PM10	Bronchitis in children, PM10	1.08	0.98	1.19	WHO 2013
PM10	Asthma symptoms in asthmatic children, PM10	1.028	1.006	1.051	WHO 2013
PM10	Incidence of chronic bronchitis in adults, PM10	1.117	1.04	1.189	WHO 2013
PM2.5	Long-term mortality, all causes	1.062	1.04	1.083	WHO 2013
PM2.5	Cardiovascular hospital admissions	1.0091	1.0017	1.0166	WHO 2013
PM2.5	Respiratory hospital admissions	1.019	0.9982	1.0402	WHO 2013
PM2.5	Restricted activity days (applied to non-working age population)	1.047	1.042	1.053	WHO 2013
PM2.5	Work days lost	1.046	1.039	1.053	WHO 2013
NO2	Bronchitic symptoms in asthmatic children	1.021	0.99	1.06	WHO 2013
NO2	Respiratory hospital admissions	1.018	1.0115	1.0245	WHO 2013
NO2	Long term mortality, all cause	1.02	1.01	1.04	Huangfu & Atkinson 2020

ECONOMIC COSTS

Air pollution causes a range of negative health impacts: chronic respiratory diseases, hospitalizations, aggravation of asthma symptoms and other health effects lead to increased health care costs; economic productivity is lowered either due to sickness and inability to work or due to an employee having to call in sick to care for an unwell child or other dependant; and shortened life expectancy and increased risk of death caused by air pollution means a welfare loss to affected people.

The basis for valuing the economic costs of the health impacts projected in this report is the valuations used in the EEA (2014) report "Costs of air pollution from European industrial facilities 2008–2012". The valuation of different health impacts of major air pollutants is given in Table A2.

The values in EEA (2014) are given for the European Union in 2010 at 2005 prices. The values were first converted to 2019 prices using European Union inflation rates, and then the valuations were adjusted for different levels of GDP per capita and costs. The basis for adjusting each cost is given in Table A2. We follow EEA (2014) in applying the same valuations in all EU countries, rather than valuing the mortality risk in higher-income member states at a higher value.

The valuations were adjusted for inflation to 2021, using GDP-weighted average inflation of EU-countries. Then the valuations were adjusted over time, and transferred to non-EU-countries, using the following logic:

- The valuation of deaths and other outcomes valued on willingness-to-pay basis was adjusted using GDP per capita at purchasing-power parity, with an elasticity of 0.8 as recommended by the OECD (2012).
- Healthcare costs were adjusted by PPP-conversion factors.
- Productivity losses (lost working days) were adjusted by GDP at market prices.

The future value of health costs is projected using the OECD (2018) long-term GDP projections for each country. Nominal GDP growth and price increases are predicted using the past statistical relationship between long-term nominal and real GDP growth (elasticity of price level with respect to GDP). The future costs are discounted at a rate of 3%/year. All required economic data was obtained from the World Bank DataBank (https://databank.worldbank.org/).

Table A2.

Valuation of health impacts for EU countries (based on EEA 2014)

EFFECT	UNIT	VALUATION, EUR, 2005 PRICES	VALUATION, EUR, 2021 PRICES	ADJUSTMENT BASIS
Asthma symptoms in asthmatic children	days	**42**	**56**	inflation
Bronchitic symptoms in asthmatic children	days	**588**	**785**	inflation
Cardiovascular hospital admissions	cases	**2,200**	**2,937**	inflation
Incidence of chronic bronchitis in adults	new cases	**53,600**	**78,597**	GDP PPP
Adult mortality	cases	**2,200,000**	**3,225,990**	GDP PPP
Minor RADs	days	**42**	**62**	GDP PPP
Postneonatal mortality	cases	**3,300,000**	**4,838,985**	GDP PPP
Respiratory hospital admissions	cases	**2,200**	**2,937**	inflation
Restricted activity days	days	**42**	**62**	GDP PPP
Work days lost	days	**130**	**177**	GDP

REFERENCES

Center for International Earth Science Information Network (CIESIN) - Columbia University 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). https://doi.org/10.7927/H4F47M65.

European Environment Agency (EEA) 2014: Costs of air pollution from European industrial facilities 2008–2012 — an updated assessment. EEA Technical report No 20/2014. https://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012

Graham et al 2012: Validated methods for flue gas flow rate calculation with reference to EN 12952-15. KEMA Nederland B.V. https://www.vgb.org/vgbmultimedia/rp338_flue_gas.pdf

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/archiv/umweltmedizin-hygiene-arbeitsmedizin-band-22-nr-2-2017

Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2020. http://ghdx.healthdata.org/gbd-results-tool.

Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2020. http://ghdx.healthdata.org/gbd-results-tool.

OECD 2012. Mortality Risk Valuation in Environment, Health and Transport Policies. https://doi.org/10.1787/9789264130807-en

OECD 2018. GDP long-term forecast (indicator). https://doi.org/10.1787/d927bc18-en

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/

World Health Organization (WHO) 2013: Health risks of air pollution in Europe-HRAPIE project. http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_proje

HEAL

www.env-health.org