5. Annexes

Annex 1

Methodology and sources for health impact modelling

This methodology details how we calculated the health impact caused by air pollution from Western Balkans coal power plants in 2016.

There are a series of discrete steps:

1. Identify coal power plants operating in the Western Balkans in 2016.
2. Source 2016 coal power plant emissions data.
3. Model the pollutant exposure resulting from the emissions from all Western Balkan coal power plants.
4. Calculate the health impacts associated with modelled pollutant exposure.
5. Attribute the health impacts to individual coal power plants.
6. Calculate the cost of the health impacts.

1

Identify coal power plants operating in the Western Balkans in 2016.

Europe Beyond Coal maintains a database of information on coal power plants.[41] From this, we identified the 16 coal plants operational in the Western Balkans in 2016 and the utility or utilities that owned these plants.

2

Source 2016 coal power plant emissions data.

In the modelling, SO_2 and NOx emissions as well as fine (PM2.5) and coarse (PM2.5-10) particle emissions from all facilities are accounted for. Data on emissions for each plant was obtained via the following sources:

Bosnia: for the Gacko, Ugljevik and Stanari plants, data on emissions were obtained from the Republic Hydrometeorological Institute, and the Ministry of Agriculture, Forestry and Water Management. For the Kakanj and Tuzla plants data comes from the Elektroprivreda Bosne i Hercegovine Annual Report on Environmental Protection for 2016.

Kosovo: plant data came from energy operator KEK's annual environmental report "Raport i gjendjes mjedisore në kek për vitin 2016".

Montenegro: data was provided by coal plant operator 'Elektroprivreda Crne Gore' Operations Department.

Macedonia: data was obtained from the national operator ELEM.

Serbia: coal plants report their emissions in the European Pollutant Release and Transfer Register (E-PRTR).[42] For our modelling, we used the E-PRTR emissions for 2016.

41. https://beyond-coal.eu/data/

42. Dataset used for modelling of SO2, NOx & dust was EPRTR v13 for 2016 data https://www.eea.europa.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-21

3

Model the pollutant exposure resulting from the emissions from all Western Balkan coal power plants.

The modelling used the Open Source EMEP/MSC-W chemical transport model[43] and the associated input datasets developed by European meteorological institutes under the Convention on Transboundary Air Pollution (CLRTAP). Specifically, for this report we relied on input data provided by EMEP/MSC-W, ECMWF and the Norwegian Meteorological Institute.

The EMEP/MSC-W is an advanced chemical-transport model that simulates air quality across Europe using spatial data on emissions from different sectors and sources, along with three-dimensional time series data on meteorological variables, such as wind speed and direction, temperature, humidity and precipitation as well as land use, topographical and other relevant geophysical data. The model is continuously developed and validated yearly by comparing predicted total pollution levels and pollution composition with measurements at dozens of ground stations.[44] All datasets and meteorological data we used cover 2016.

For the first time in this report series, the total air quality and health impacts from all the studied power plants were estimated using the new, high-resolution EMEP grid.[45] We used two simulations[46] that singled out SO2 and NOx emissions as well as fine (PM2.5) and coarse (PM10) particle emissions from all facilities.

The MSC-W model is a regional-scale model. The local pollutant concentrations at the most affected locations would be much higher than indicated by the value for the whole grid cell, but most of the health impacts are associated with the long-range transport of pollution. Long-range pollution exposes millions of people to small additional concentrations, causing disease and mortality.

43. Version 4.17a

44. EMEP MSC-W model performance for acidifying and eutrophying components, photo-oxidants and particulate matter in 2016: http://emep.int/publ/reports/2018/sup_Status_Report_1_2018.pdf

45. A 0.1 x 0.1 degree regular longitude-latitude grid (as opposed to the lower resolution 50 x 50 km polar stereographic grid used in previous years) - this represents an approximately 26 fold increase in model resolution.

46. A simulation with all emissions from all sectors - known as the baseline - and a simulation with the emissions from the coal power stations removed (with all other emissions left unchanged). The difference between the two simulations identifies the impact of coal power stations on air quality.

4

Calculate the health impacts associated with modelled pollutant exposure.

The methodology for estimating mortality and morbidity caused by emissions of coal-fired power plants in this report followed the recommendations of experts from Europe and North America, convened by WHO Europe to assess the health impact of air pollution in Europe. (see HRAPIE[47] recommendations).

Exposure to primary and secondary particulate matter, ozone and nitrogen dioxide caused by emissions from the studied plants was estimated using the modelling process described earlier.

The health impacts resulting from modelled pollutant concentrations were evaluated by assessing the resulting population exposure, based on high-resolution gridded population data for 2015 from NASA's SEDAC Gridded Population of the World v.4.[48] We then applied the WHO HRAPIE recommendations for health endpoints and for concentration-response functions to assess the health impact.[49] The extended set of pollutant-outcome pairs recommended for inclusion in the total effect (HRAPIE groups A* and B*) was used.[50] Affected fractions of the population were applied evenly to all grid cells. Required baseline health data were obtained from WHO databases[51] as well as from a technical guidance paper on implementing HRAPIE recommendations.[52]

47. http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide

48. http://beta.sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density

49. Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide

50. Groups A* and B* are recommended by HRAPIE for estimating the total effect as one option for impact analyses, representing the extended set of effects. Groups B* and B come with higher uncertainty than groups A* and A.

51. WHO Global Health Estimates, 2012, http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html

52. Holland, M. (2014), Implementation of the HRAPIE Recommendations for European Air

Pollution CBA work, http://ec.europa.eu/environment/air/pdf/CBA%20HRAPIE%20implement.pdf

The health impacts in each grid cell were calculated as:

[number of cases] = [population in grid cell] * [affected population fraction] * [baseline incidence] * [change in pollutant concentration] * [concentration-response factor],

Baseline incidence refers to the incidence or prevalence of the studied impact in the population - excluding the impact of the modelled coal emissions; e.g. new cases of chronic bronchitis per 100,000 people.

Affected population fraction refers to the percentage of the total population that the impact estimate is applied to e.g. population at or above 30 years of age for chronic mortality. The fractions were calculated for the total population and applied to all grid cells.

Change in pollutant concentration refers to the change in predicted concentrations between the baseline and the simulations.

Concentration-response factor refers to the percentage increase in cases per increase in pollutant concentration derived from scientific studies, e.g. 6.2% increase in mortality when PM2.5 concentrations increase by 10μg/m^3 over a long period. These results for each grid cell are then summed over the geographic area for which impacts are being calculated.[53]

Table 1 Concentration response functions for mortality

Increase in risk for a 10μg/m^3 increase concentration core mortality functions without infant mortality to be added for total impact with likely overlap of 33% between PM2.5 and NO2 effect, Ozone concentration refers to summer period (April to September) average.

Impact	Subgroup	Pollutant	Central	Low	High
All cause natural mortality from chronic exposure	Over 30 years	PM2.5	6.20 %	4 %	8.30 %
All cause natural mortality from acute exposure	All ages	O_3	0.29 %	0.14 %	0.43 %
All cause natural mortality from chronic exposure	Over 30 years	NO2	5.5 %	3.1 %	8.0 %
Infant mortality (HRAPIE group B*)	1 month to 12 months	PM2.5	4.0 %	2.0 %	7.0 %

53. Natural mortality in the over 30s, eliminating deaths under that age, and any death from accidental and intentional causes (suicides, murders etc.).

Table 2 Concentration response functions and population and morbidity data for non-fatal health impacts

Pollutant	Effect	Affected population fraction	Incidence rate	Response function	Concentration increase (10µg/m³)	HRAPIE group
PM10	Incidence of chronic bronchitis, population aged over 27 years	67.6 %	0.39 %	11.70 %	10	B*
PM10	Bronchitis in children, ages 6-12 years	7 %	18.6 %	8 %	10	B*
PM10	Incidence of asthma symptoms in asthmatic children, ages 5-19 years	0.6 %	62 %	2.8 %	10	B*
PM2.5	Respiratory hospital admissions, all ages	100 %	1.165 %	1.9 %	10	A*
PM2.5	Cardiac hospital admissions, all ages	100 %	2.256 %	0.91 %	10	A*
PM2.5	Restricted activity days (RADs)	100 %	19 %	4.7 %	10	B*
PM2.5	Work days lost, working age population	42.5 %	9.4 %	4.6 %	10	B*
Ozone (SOMO35)	Minor restricted activity days, all ages	100 %	7.8 %	1.54 %	10	B*
Ozone (SOMO35)	Respiratory hospital admissions, ages over 64 years	16.4 %	2.2 %	0.44 %	10	A*
Ozone (SOMO35)	Cardiovascular hospital admissions, ages over 64 years	16.4 %	5 %	0.89 %	10	A*
NO2	Bronchitis in children, ages 5-14 years	0.5 %	1.52 %	2.1 %	1	B*
NO2	Respiratory hospital admissions, all ages	100 %	1.165 %	1.8 %	10	A*

The mortality estimates include the effect of direct NO2 exposure, in line with WHO recommendations. The central and low estimates of mortality in this report (low range with a 95% confidence interval) only include 67% of the NO2 mortality effect based on a single pollutant risk model. This is because of possible overlap with PM2.5 health impacts identified by the WHO (HRAPIE project report).

Only grid cells with background concentrations of NO2 above 20 µg per m^3 were reported in the AQ e-Reporting dataset[54] from European monitoring stations, as well as grid cells for which the MSC-W simulations yielded concentrations above 20 µg per m^3 were included to calculate NO2 mortality.

Our analysis, based on WHO Europe's latest recommendations from 2013, suggests that ~ 1% of the damage caused by power coal power stations in the Western Balkans is linked to exposure to NO2. There is comparatively more research on the effects of fine particles than NO2 exposure, so our NO2 results carry a higher level of uncertainty. A more recent review has been provided by COMEAP (2018)[55] on behalf of the UK's Department for Health and Social Care. It gives a detailed account of the uncertainties involved in NO2 assessments.

5

Attribute the health impacts to individual coal power plants.

For the purpose of further simulations, the power plants were grouped into two geographical clusters and a simulation was carried out separately for SO2 and NO2 emissions from each cluster. Due to limitations on computational availability, these additional simulations were carried on the lower resolution 50 x 50 km polar stereographic grid. This provided a total of six simulations, including two baseline simulations with all clusters and without all clusters.

The pollution exposure and health impacts resulting from one unit of emissions of SO2 and one unit of NO2 from each cluster were then calculated and applied to the emissions from each facility in the cluster. This assigned the estimated health impacts caused by SO2 and NO2 to each facility.

54. European Environment Agency, Air Quality e-Reporting (AQ e-Reporting). The European air quality database. https://www.eea.europa.eu/data-and-maps/data/aqereporting-8

55. https://www.gov.uk/government/publications/nitrogen-dioxide-effects-on-mortality

To assign the primary PM2.5 and PM10 emissions impact, we used the existing country-by-country emissions-to-exposure values from the CAFE CBA methodology. Primary PM emissions are responsible for a small share of the total health impacts, therefore we did not do an additional set of cluster runs for them – we believe the added value would have been negligible.

This approach is similar to that used in the European Commission's 'Clean Air For Europe (CAFE) Cost Benefit Analysis' methodology[56] as well as the European Environment Agency's 'Revealing the costs of air pollution from industrial facilities in Europe' report, improving upon it in some respects:

- Atmospheric modelling is carried out specifically for the studied coal-fired power plants. Earlier approaches to plant-level health impact estimates relied on modelling results, including emissions from all sectors, using sectoral adjustment factors to make the estimates more appropriate for power plants.
- PM10 concentrations were simulated directly, rather than being calculated from PM2.5 using a fixed ratio.
- The influence of coal-fired power plants on ambient NO2 levels is included. Earlier work only looked at the impacts on PM2.5 and ozone, but the WHO recommendations now recognise that NO2 exposure also has long-term health impacts.

6

Calculate the cost of the health impacts.

The economic valuation of human health impacts is a tool to estimate an acceptable cost for avoiding those impacts. The approach used by the European Commission and the European Environment Agency[57] as well as the World Health Organization[58] and adopted in this paper includes both direct costs, such as health care costs and lost economic output due to absence from work, as well as a measure of people's willingness to pay to avoid the risk of death or disease. The premise is that since health risks

56. AEA Technology Environment (2005), Methodology for the cost-benefit-analysis for CAFE. Volume 2: Health Impact Assessment. http://ec.europa.eu/environment/archives/cafe/pdf/cba_methodology_vol2.pdf

57. AEA Technology Environment 2005: Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas. Tables 4 and 5. http://ec.europa.eu/environment/archives/cafe/activities/pdf/cafe_cba_externalities.pdf

58. WHO European Region (2015), Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2015/economic-cost-of-the-health-impact-of-air-pollution-in-europe

from air pollution affect all citizens, and individual people do not have the choice of spending money to significantly reduce toxic power plant emissions, a government's willingness to direct resources to reduce health impacts from air pollution should be the same as the willingness of the people it governs.

The costs associated with the health impacts of Western Balkan coal-fired power plants are estimated based on the cost values used in 2014 impact assessments for the EU Clean Air Policy Package.[59] They were updated from 2005 prices (the reference year for the values in the report) to 2016 prices using the following methodology:

- For health impacts that occurred within the EU, the 2005 prices were adjusted according to Actual Individual Consumption, real expenditure per capita (EU).[60]
- For health impacts that occurred within the six Western Balkan countries, 2005 prices were adjusted by the ratio of the 2016 population-weighted Western Balkan GDP per capita (power purchasing parity - PPP) to the 2005 EU GDP per capita (PPP)[61]. An elasticity of 0.8 was applied to account for the variation in willingness to pay as incomes change.
- For health impacts that occurred outside the EU and Western Balkan countries, 2005 prices were adjusted by the ratio of the 2016 population-weighted GDP per capita (PPP) value for Turkey, Ukraine and Egypt[62] to the 2005 EU GDP per capita (PPP). An elasticity of 0.8 was applied to account for the variation in willingness to pay as incomes change.

59. Amann, M. (ed.) (2014), The Final Policy Scenarios of the EU Clean Air Policy Package. International Institute for Applied Systems Analysis IIASA. http://ec.europa.eu/environment/air/pdf/TSAP.pdf as well as Holland, M. (2014), Cost benefit Analysis of Final Policy Scenarios for the EU Clean Air Package. http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf

60. Price development as reflected in Eurostat indicator "Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates [prc_ppp_ind]" for Actual Individual Consumption, real expenditure per capita (EU-28). http://ec.europa.eu/eurostat/data/database

61. Population and GDP per capita (PPP) figures from the world bank. https://data.worldbank.org/indicator/ny.gdp.pcap.pp.cd & https://data.worldbank.org/indicator/SP.POP.TOTL

62. These three countries account for the large majority of the health impacts that occur outside of the EU and the Western Balkans.

Table 3 Monetary values applied to mortality and morbidity endpoints for EU, the Western Balkans and for other countries

	EU		Western Balkans		Other countries	
Health impact	Median monetary value, EU average Euro 2016 prices	High monetary value average, EU Euro 2016 prices	Median monetary value, WB PPP adjusted average Euro 2016 prices	High monetary value, WB PPP adjusted average Euro 2016 prices	Median monetary value, Other countries PPP adjusted average Euro 2016 prices	High monetary value, Other countries PPP adjusted average Euro 2016 prices
Mortality from chronic or acute exposure, VSL	1,335,915	2,720,854	657,826	1,339,792	774,967	1,578,374
Infant mortality (1-12 months)	1,960,976	4,044,512	965,616	1,991,583	1,137,567	2,346,231
Hospital admissions due to respiratory or cardiovascular symptoms	2,721		1,340		1,578	
Chronic bron-chitis in adults	65,693		32,348		38,108	
Work days lost, working age population	159		78		92	
Restricted activity days	113		56		65	
Minor restricted activity days	51		25		30	
Bronchitis in children	721		355		418	
Asthma symptom days in asthmatic children	51		25		30	

Annex 2

Health impacts and associated health costs

Table 1 Modelled annual health impacts and health costs occurring in each EU country due to air pollution emissions from Western Balkan coal plants, emissions in 2016

Country	Premature deaths	Infant mortality (1-12 months)	Bronchitis in children	Asthma symptom days in asthmatic children	Chronic bronchitis in adults	Hospital admissions due to respiratory or cardiovascular symptoms	Restricted activity days	Work days lost, working age population	Total cost high case (€)	Total cost median case (€)
Austria	48	0	94	1,286	28	57	77,978	20,676	141,860,738	75,596,771
Belgium	3	0	5	67	1	1	4,100	844	7,644,144	4,056,802
Bulgaria	253	0	275	2,697	96	129	261,580	53,856	728,856,412	377,489,289
Croatia	164	0	263	2,621	76	99	213,809	50,665	478,974,523	251,299,359
Cyprus	4	0	7	72	2	3	5,891	1,213	10,993,301	5,834,017
Czech Republic	54	0	87	843	29	45	81,191	30,474	158,866,136	84,409,709
Denmark	0	0	1	9	0	0	648	133	1,237,098	656,295
Estonia	0	0	0	5	0	0	341	70	906,674	471,706
Finland	0	0	1	12	0	0	575	118	1,043,984	560,109
France	27	0	76	949	17	20	48,623	10,011	81,060,921	43,415,055
Germany	72	0	117	1,510	39	59	105,091	38,527	212,178,903	112,459,955
Greece	171	0	309	3,855	97	128	265,543	54,672	504,415,742	267,553,433
Hungary	266	0	362	3,818	110	222	310,082	67,454	770,417,823	401,580,843
Ireland	0	0	0	4	0	0	171	35	197,116	109,379
Italy	370	0	661	8,517	223	228	592,223	121,932	1,095,395,710	582,341,360
Latvia	1	0	1	14	0	1	1,228	253	3,248,970	1,687,869
Lithuania	3	0	5	49	1	3	3,890	739	8,743,114	4,581,861
Luxembourg	0	0	1	10	0	0	531	102	717,231	391,554
Malta	2	0	6	87	2	2	4,594	500	6,296,051	3,421,513
Netherlands	3	0	8	100	2	2	5,574	1,539	9,011,987	4,844,175
Poland	106	0	201	2,118	59	101	167,492	48,827	313,639,231	166,804,994
Portugal	0	0	1	13	0	0	769	158	1,340,935	715,437
Romania	380	1	620	6,013	171	239	486,190	75,909	1,107,492,473	579,444,102
Slovakia	45	0	91	933	26	44	74,945	16,302	134,724,572	71,737,734
Slovenia	24	0	44	417	15	21	40,931	11,649	71,868,875	38,427,086
Spain	12	0	24	306	8	8	21,051	4,334	34,407,949	18,461,939
Sweden	0	0	1	12	0	0	153	1,388,386	739,214	738,472
United Kingdom	4	0	10	131	2	2	1,095	11,635,426	6,217,825	5,961,398

Note: numbers are rounded, omitting the decimal places. Thus, sum of numbers might not add up.

Table 2 Modelled annual health impacts and health costs occurring in each Western Balkan country due to air pollution emissions from its own coal plants, emissions in 2016

Country name	Premature deaths	Infant mortality (1-12 months)	Bronchitis in children	Asthma symptom days in asthmatic children	Chronic bronchitis in adults	Hospital admissions due to respiratory or cardiovascular symptoms	Restricted activity days	Work days lost, working age population	Total cost high case (€)	Total cost median case (€)
Serbia	570	1	1,042	10,682	303	439	853,836	175,795	1,682,648,627	890,007,062
Bosnia and Herzegovina	334	0	616	6,410	181	276	521,436	107,358	985,388,752	522,794,194
Macedonia	104	0	216	2,060	46	70	140,355	4,036	302,709,554	158,402,008
Kosovo	99	0	180	1,540	42	61	124,144	25,560	288,102,961	150,691,157
Albania	96	0	300	2,958	46	79	161,035	33,155	286,481,092	152,333,167
Montenegro	35	0	64	548	15	23	44,491	9,160	102,789,489	53,784,642

Note: numbers are rounded, omitting the decimal places. Thus, sum of numbers might not add up.

Table 3 Modelled total annual health impacts and total health costs for each Western Balkan coal plant, emissions in 2016 total damage for all regions

Plant name	Premature deaths	Infant mortality (1-12 months)	Bronchitis in children	Asthma symptom days in asthmatic children	Chronic bronchitis in adults	Hospital admissions due to respiratory or cardiovascular symptoms	Restricted activity days	Work days lost, working age population	Total cost high case (€)	Total cost median case (€)
Gacko	158	0.3	331	3371	83	115	235,666	46,306	359,334,036	189,997,369
Kakanj	390	0.7	835	8,494	201	309	602,006	116,864	890,667,791	471,599,963
Stanari	11	0.0	23	233	6	9	15,285	2,998	24,728,867	13,038,542
Tuzla	274	0.5	586	5,961	141	215	423,758	82,285	625,294,558	331,131,952
Ugljevik	635	1.2	1,362	13,845	328	494	990,727	192,236	1,450,692,632	768,524,979
Kosovo A	22	0.1	67	651	13	18	36,076	6,066	46,865,741	24,917,302
Kosovo B	63	0.2	142	1,421	35	32	93,839	18,185	131,983,308	69,830,265
Pljevlja	133	0.2	285	2,894	68	106	20,4449	39,686	303,087,731	160,455,296
Bitola	181	0.5	534	5,160	95	154	317,677	52,709	386,325,572	206,016,066
Oslomej	2	0.0	5	48	1	1	2,936	493	3,614,401	1,926,171
Kolubara A	57	0.1	117	1,194	31	35	8,4161	16,761	129,433,698	68,412,190
Kostolac A	381	0.7	816	8,295	196	299	590,581	114,625	868,613,242	460,032,698
Kostolac B	657	1.2	1406	14,301	339	514	1,017,706	197,612	1,498,451,744	793,565,162
Morava	21	0.0	43	440	11	14	30,753	6,081	47,197,468	24,947,484
Nikola Tesla A	600	1.1	1,278	13,003	310	473	915,677	178,138	1,366,077,086	722,995,776
Nikola Tesla B	322	0.6	686	6,983	166	257	488,766	95,114	733,916,837	388,301,602

Note: numbers are rounded, omitting the decimal places. Thus, sum of numbers might not add up.

Table 4 Impact Matrix table from total annual health impacts and total health costs for each Western Balkan coal plant, emissions for year for all modelled regions

	EU	Western Balkans	Other countries
Gacko	53%	32%	16%
Kakanj	53%	32%	16%
Stanari	53%	32%	16%
Tuzla	53%	32%	16%
Ugljevik	53%	32%	16%
Kosovo A	38%	32%	30%
Kosovo B	38%	32%	30%
Pljevlja	52%	32%	15%
Bitola	38%	28%	34%
Oslomej	38%	28%	34%
Kolubara A	52%	32%	15%
Kostolac A	52%	32%	15%
Kostolac B	52%	32%	15%
Morava	52%	32%	15%
Nikola Tesla A	52%	32%	15%
Nikola Tesla B	52%	32%	15%