The Dirty Legacy of Coal

GREENPEACE

Content

Intro

Coal is the single biggest driver of anthropogenic climate change across the globe[1]. Burning coal generates a third of the CO_2 emissions resulting from human activities. With almost 40% of the energy worldwide[2] coming from this type of fossil fuel, the phase-out of coal is key to slowing down climate change and averting a mass-scale ecological catastrophe. This is our chance to keep the global temperature rise below 1.5°C in order to avoid the existential threat to humanity which is already a harsh reality for many around the globe in the form of devastating floods, severe droughts, destructive fires and crops failure.

With a 40% (in summer) to 60% (in winter)* coal-generation in its electricity mix, Bulgaria is one of the EU countries still heavily reliant on coal. What is more, the system is vastly dependent on an aging and severely polluting fleet, burning local fuel with high concentrations of sulphur and substantial contents of dust, released in the form of sulphur dioxide and particulate matter in the incineration process. In parallel to intensifying the climate crisis, coal-fired power plants are a known source of water and air pollution to local and regional environments.

That is why Greenpeace - Bulgaria set out to research the impacts on water and air of the Bobov dol coal-fired power plant (CFPP) in the region of the village of Golemo Selo in Western Bulgaria. With a capacity of 1716 MWth (630 MWe) the facility constitutes 14% of the total installed coal-based electricity generation capacity[4], and provides around 9% of the gross energy production by thermal power plants[5] and 4% of the overall gross energy production[6] in Bulgaria. Built in 1975, it is a symbolic image of an outgoing industry which clings on to the power structures of an unreformed energy system, availing of last-century technologies which have normalized destructive levels of pollution.

The Bobov dol CFPP was privatized in 2008 in a motion which made complete the “Kovachki” coal empire, related to a well-known energy tycoon[7], currently self-presented simply as an energy consultant. In the past several years the addition of alternative fuels like waste and biomass has been a trend for the ageing coal power plants connected to Kovachki in an attempt to alleviate the economic weight of rising CO_2 emission prices and plunging coal profitability. Bobov dol CFPP makes no exception: in 2019 it used more than 2,4 million tonnes of hard fuel, made up of 1,65 million tonnes of coal, 748 thousand tonnes of biomass also qualified as waste depending on its contents, and 31 thousand tonnes of waste labeled as non-hazardous[8]. On 9 April 2019 the power plant received a new Integrated Permit introducing the use of alternative fuels[9] and prior to this moment the co-incineration of non-hazardous waste was permitted by the Ministry of Environment and Water in an unofficial and unregulated procedure[10] for experimental burning, starting from 12 November 2018 for a period of 6 months. In January 2019 already, the final ash disposal site Kamenik received a new Integrated Permit, expanding the list of types of waste it is allowed to receive with ashes produced from the co-incineration of coal with waste and biomass[11].

The process of coal power generation relies on vast quantities of water - a precious resource, growing ever more scarce as a result of the climate emergency. Forecasts for an ever reducing water availability and an increasing competition for the resources at hand are quickly becoming a reality. In the same time, the largest amount of water use in Bulgaria supplies only the cooling needs in the energy production sector[12] - with the figure amounting to 75% of the total water use in 2018. On top of that, in terms of water consumption coal is the least efficient energy source, with some Bulgarian coal plants ranking amongst the worst on this indicator[13]. Additionally, coal takes a serious

In recent years there has been a downward trend in coal electricity generation in Bulgaria due to decreasing market competitiveness of the power plants[3].

toll on the quality of water at every step of the way: from mining, to burning, to storage of the waste ashes - which are typically deposited in large ponds associated with long-term negative impacts on the environment due to insufficient restoration plans and loose institutional control.

That is why the study on water pollution was carried out to determine the then composition, and the variation in composition over time, of waste streams generated by the Bobov dol CFPP and its adjacent ash storage site, known as a black lake, released into the Razmetanitza River, as well as those released from the larger, long-term, Kamenik ash disposal site to Kamenishka river, a tributary to the Razmetanitza river.

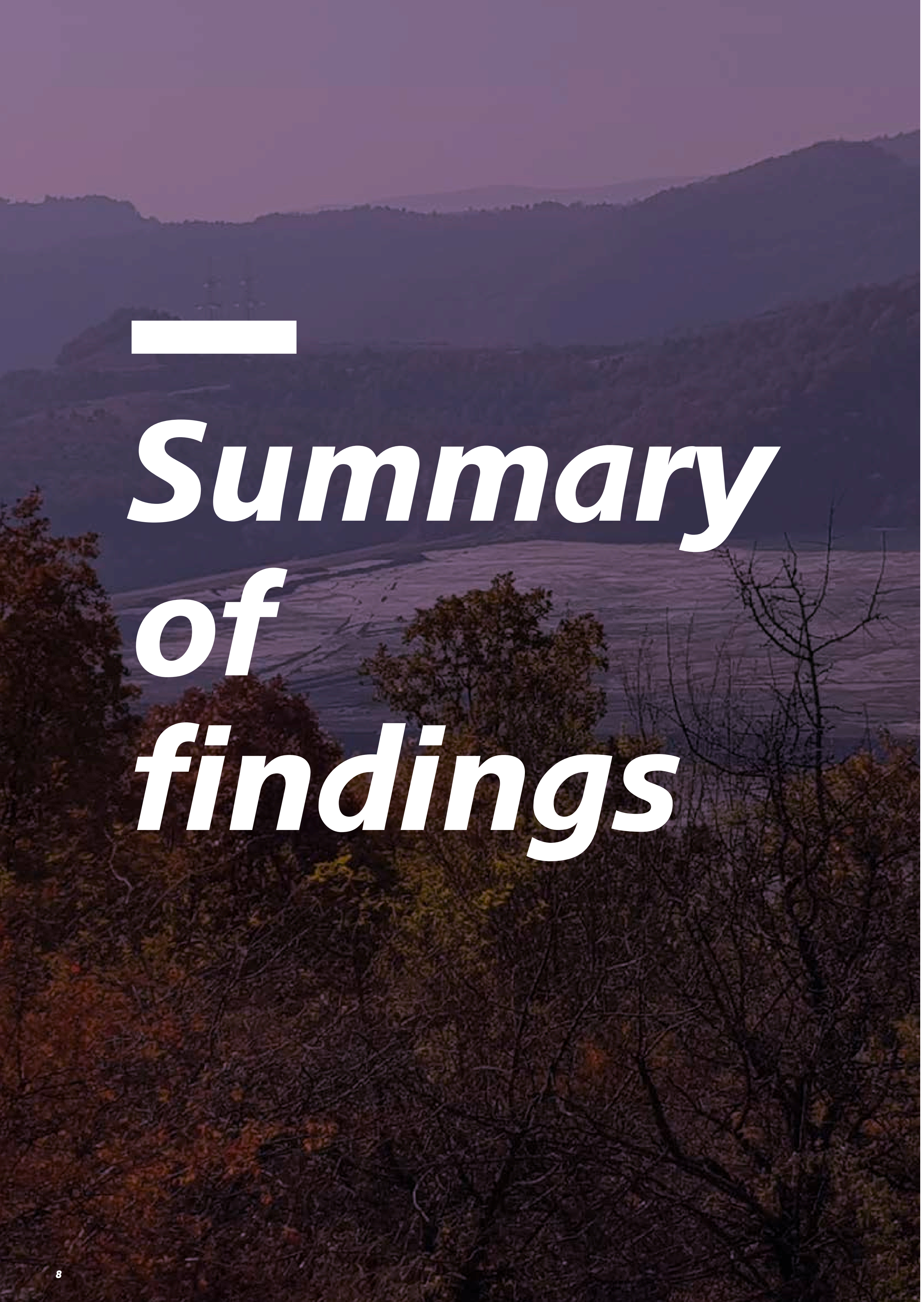
Even more widely established, coal power plants are a known source of air pollution - an increasing amount of scientific evidence is pointing out that this invisible threat is affecting literally every part of the human body[14]. Breathing polluted air causes discomfort, shortness of breath, cough, eye irritation, and long-term exposure could lead to serious illnesses like asthma, lung cancer, heart disease, illnesses of the neuro- and reproductive systems. The areas around power plants usually display higher levels of sulfur dioxide SO_2 and particulate matter PM_{10} and $PM_{2,5}$ than areas farther away.

For that reason the report features a study on air pollution which describes the results of a three-month air pollutant monitoring survey carried out at Golemo Selo. Monitoring of ambient air pollutants including nitrogen dioxide NO_2 and PM_{10} was undertaken from 21st February 2019 until 22nd May 2019. The analysis also calls attention to results of a previous long-term monitoring survey of nitrogen dioxide NO_2 and sulphur dioxide SO_2 carried out by Greenpeace Bulgaria as well as official monitoring carried out by the Bulgarian Executive Environment Agency (EEA).

The results of the study confirmed frequent releases of contaminated waste waters to the local environment from different locations around the Bobov dol CFPP. An operational cycle which ends in an open-air ash storage facility requiring consistent management for decades past the termination of power generation, leaves a legacy of pollution and spoiled natural environments to last long beyond the era of coal.

Also, the operation of the power plant creates a health hazard for the communities living in its vicinity through the constantly elevated background levels of some pollutants and the spikes in the concentration of others in specific parts of the day. Moreover, the regulations and institutional capacity currently in place are insufficient to control and prevent incidents of pollution, leaving both people and the environment hostage to the detrimental impacts of the coal industry.

The aggregation of direct harmful impacts to people and the environment, the dirty heritage to the local territories and the global repercussions of the climate crisis is an urgent call for a future proof transformation to protect our water resources and increase our adaptation capacities. A nation-wide coal phase-out date would provide a frame for a well-paced plan for a transition to a decentralized energy system based on renewable energy solutions. This is a crucial first step in assuming responsibility to alleviate the climate crisis and rapid biodiversity loss - global crises with a variety of local implications. With the world at a crossroads, there is an opportunity to build economies and communities which thrive while respectful to the environment. A planned transition would provide for diversification of local economies toward future-proof activities. And last but not least, a just transition would provide workers new job opportunities which do not require a compromise with their own health.
As affected regions would have to deal with the dirty legacy of coal for generations, a transition, despite being long overdue, is necessary more than ever.



Summary of findings

Waste waters containing a range of metals and metalloids, associated with coal fly ashes, at elevated concentrations are routinely released to the local environment from sites where ashes generated by the Bobov Dol CFPP are stored. These include wastewaters released to a tributary to the Razmetanitza River from the lower equalizer facility (LEF) which is situated immediately below the dike of the Kamenik ash disposal site.

The study findings suggest that waste streams from the Bobov Dol CFPP and/or its associated black lake ash storage site are impacting the quality of river water and sediments of the Razmetanitza River. The study also found evidence which indicated the release of substantial quantities of ash into the Razmetanitza River from the vicinity of the CFPP and black lake ash storage site on 21 of May 2019.

The EU and WHO daily mean standard for particulate matter PM10 of 50 µg/m^3 was exceeded on five occasions in the data analysed by the study. One of these was recorded by the mobile monitoring station of the EEA and four - by the pDR machine deployed by Greenpeace - Bulgaria. The monitoring devices operated for different and relatively brief periods and therefore the results indicate a potential problem as only 35 exceedances are permitted annually according to the EU legislation.

There were also a further 11 exceedances of the WHO 24-hour mean guideline for sulphur dioxide SO_2 of 20 µg/m^3. The EU 1-hour mean standard for sulphur dioxide SO_2 of 350 µg/m^3 was exceeded once in the data analysed by the study and recorded by the EEA mobile station. 24 exceedances are permitted annually. Monitoring of this pollutant was only performed for two 14-day-long periods, and it is therefore likely that further exceedances of these standards would be recorded during the calendar year.

There were no breaches of the EU and WHO air quality standards for nitrogen dioxide or ozone during the periods of monitoring. However the short-term monitoring data do not allow an assessment for exceedances of the annual mean air quality standards. The AQMesh device, deployed by Greenpeace-Bulgaria, measured relatively high concentrations of nitrogen dioxide NO_2 and ozone O^3 compared to the other monitoring stations involved in the study. A direct comparison is impossible due to the different locations and monitoring periods. The period mean of NO2 (41 µg/m^3) is higher than the annual-average standard (40 µg/m^3). Therefore, if concentrations outside the monitoring period remain at similar levels the annual mean NO_2 standard could be expected to have been exceeded.

There is a well pronounced diurnal cycle of these two pollutants with nitrogen dioxide NO_2 levels peaking and ozone O_3 levels falling during the day and vice versa during the night. The NO_2 night-time minima do not fall below 15 µg/m^3. In a rural area such as Golemo Selo, where there are limited sources of NO_2 at night, these elevated concentrations at night suggest that the emissions from the Bobov dol CFPP, which operates on a near continuous basis, raise the background concentration of this type of pollution in the region.

For further details:

Technical report on water pollution research on Bobov dol CFPP[15]

Technical report on air pollution research on Bobov dol CFPP[16]

Policy recommen-dations

Investigate pollution and sanction perpetrators accordingly

Until measures are put in place to prevent releases of contaminated wastewaters and solid wastes from the Bobov Dol CFPP and its ash storage sites, there will remain severe ongoing impacts on the quality of local surface water environments. An investigation into the apparent release of substantial quantities of ash into the Razmetanitza River during May 2019, and whether similar releases have occurred at other times, must be conducted. The investigation should recommend preventative measures with the aim of putting an end to any such release in the future, and these measures must be implemented without delay.

Prevent pollution through stricter regulations

Stricter regulations need to be effectively put in place in order to prevent pollution and improve the ecological status of the Razmetanitza River. With significant water scarcity projected in the near future due to the effects of climate change in the West Aegean River Basin, it is highly irresponsible to tolerate damaging levels of pollution.

Monitor, analyze and publicize data

The analyses of air quality measurements reveal concerning evidence of breaches of both EU and WHO standards for pollutants like particulate matter PM_{10} and sulphur dioxide SO_2, as well as elevated background concentrations of nitrogen dioxide NO_2 in the region around the Bobov dol CFPP. A polluter of this magnitude should be responsible to provide regular monitoring of air pollution, conducted by an independent body to ensure a timely, transparent and public evaluation of the data. Ultimately, there is a pressing need to address the root causes of the problem and prevent air pollution at its source.

Put environment and climate at the core of the permitting procedure

The requirements in the permitting procedure for the operation for coal-fired power plants need to live up to the challenges of prevention of pollution, environmental degradation and climate change acceleration, as opposed to being tailored to the capabilities of morally and technically outdated installations.

Water

Bobov dol CFPP is located on the banks of the Razmetanitza River, a tributary to the Dzherman River, which flows into the Struma River - the central water body of the West Aegean River Basin. The power plant is authorized to release filtered waste water into Razmetanitza via two official discharge points on the black lake[17] - the ash storage site adjacent to the power plant. Fly ash is transferred from the plant to this site for temporary storage and treatment. It is subsequently transported via a 5-km-long conveyor belt to the Kamenik facility - the dam-like final ash disposal site of Bobov dol CFPP, situated in the nearby mountain between the villages of Kamenik and Mali Varbovnik. Some 10 km downstream from the power plant Razmetanitza receives the waters from the Kamenishka River which originate from a facility below the dike of Kamenik.

Thermal electric power plants - Bobov dol CFPP being the biggest installed capacity in the region, are single-handedly responsible for 6% of the total emissions of industrial waste waters[18] on the whole territory of the river basin. On a more local scale, Bobov dol CFPP, with its depot Kamenik, is one of the two[19] emitters of industrial waste waters into the Razmetanitza River, the other being the coal mines further upstream. Domestic waste water is discharged from two urban canalization networks[20] in the town of Bobov dol.

Despite its ecological state rated as moderate, and its chemical state - as good, according to the River Basin Management Plan (2016-2021) of the West Aegean River Basin, Razmetanitza rates poorly in the following years with its ecological state deteriorating to the worst possible status. The EU Water Framework Directive - the legal ground for RBMPs, has a 5-category classification scheme for surface water ecological status depending on the rate of human activity-induces pressure: high, good, moderate, poor and bad. Although the river maintains a "good" chemical status through the years, its ecological status and potential are constantly rated as "very bad" in the Annual Bulletins on Water Monitoring in 2017[21], 2018[22], and 2019[23]. Reducing and eventually eradicating pollution must be prioritized in order to improve the condition of affected water bodies, especially in light of the projected water scarcity in the near future due to climate change[24].

Sample description

Three visits were made to the Bobov Dol CFPP and its surrounding infrastructure between November 2018 and May 2019, and a range of samples were collected during each visit.

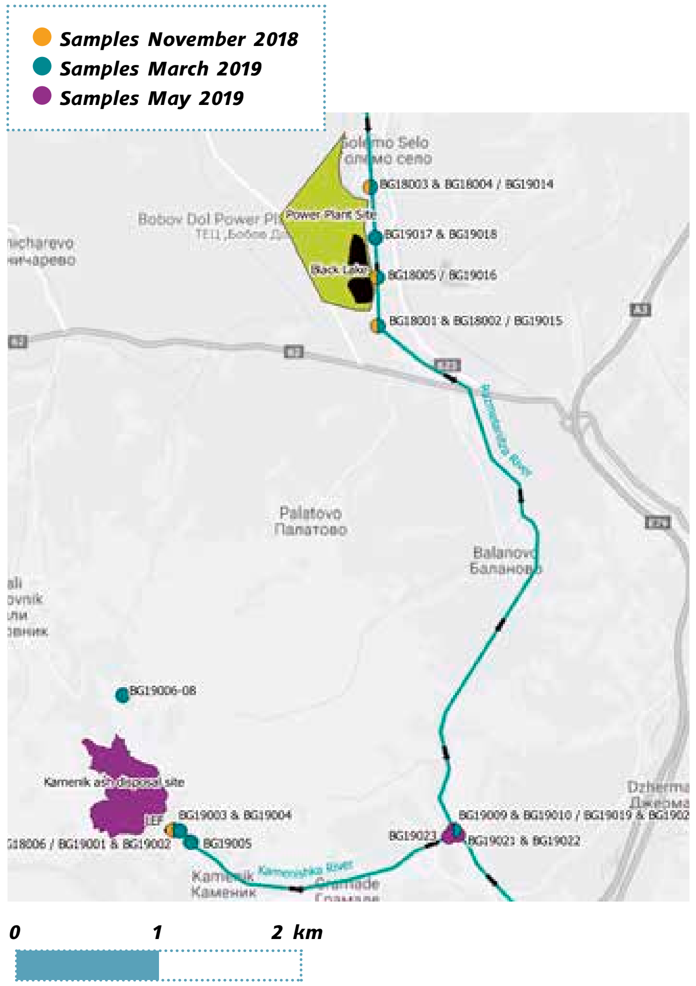
Table 1. List of visits, number of samples and descriptions of locations

8-9 Nov 2018	*6 samples*	*Collected mainly from the Razmetanitza River in the immediate vicinity of the CFPP itself and the black lake.*
11-13 Mar 2019	*18 samples*	*Collected around the CFPP but also with a more detailed focus on waste going to and exiting from the Kamenik ash disposal site.*
21 May 2019	*5 samples*	*Collected with a particular focus on waters and sediments both immediately upstream and downstream of the confluence of the Kamenishka River with the Razmetanitza River.*

Coal contains a wide range of metals and metalloids at various concentrations, some at relatively high levels and others as trace components[25]. This includes toxic elements such as arsenic and mercury, as well as other elements such as aluminium, calcium, magnesium, manganese, potassium and rubidium and strontium[26, 27]. The composition varies widely between different sources of coal.

When burned, metals and metalloids are released from within the coal. A fraction is released in flue gases, though in general the main fraction will be retained within the fly ash, in many cases at higher concentrations than in the unburned coal[28].

Figure 1. Map of locations of collection of samples



During combustion, metals and metalloids within the coal undergo changes in their chemical form, which can result in being more labile to leaching from the resulting ash compared to leaching from the unburned coal[29, 30]. Following disposal of fly ashes, metals and metalloids can leach over time to varying degrees. Resulting leachates can be contaminated with both major and trace metals/metalloids, which, if released, can contaminate groundwater and surface waters[31, 32, 33, 34]. Releases of toxic trace elements such as arsenic and mercury can have impacts on the environment and human health. Releases of major metals such as calcium, potassium and strontium within wastewaters can increase the salinity, and impact the quality, of receiving waters environments, which could have ecological implications depending on the mix of metals involved and the final concentrations within the receiving waterbody[35, 36].

The case of the black lake of Bobov dol CFPP

Samples

Wastewater from the production cycle of the Bobov Dol CFPP is discharged from the adjacent black lake via two official discharge points into the Razmetanitza River. In November 2018, samples of river water and sediment were collected from the Razmetanitza River both upstream (BG18003-04) and downstream (BG18001-02) of the two discharge points, though unfortunately, the river water sample collected downstream of the discharge points broke in transit and could not be analysed. In addition, a sample of wastewater was collected directly from the higher of the two discharge points (BG18005). The second wastewater discharge point, situated approximately 150 m further downstream, could not be accessed.

The site was revisited in March 2019 and the locations listed above were resampled, including the same (upper) wastewater discharge point (BG19016) and river water from the Razmetanitza River both upstream (BG19014) and downstream (BG19015) of the two discharge points.

Figure 2: Map of locations of collection of samples near the Bobov dol CFPP`

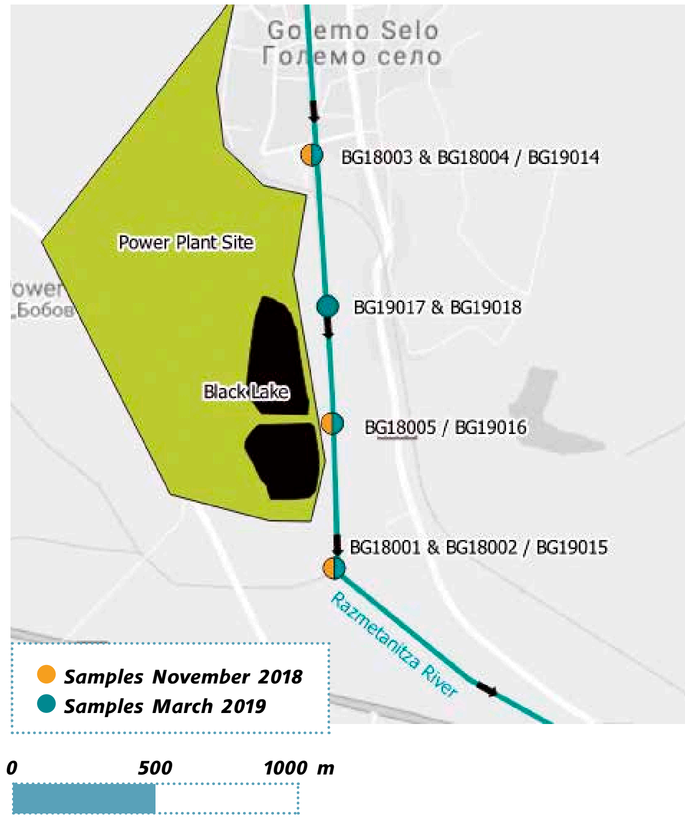


Table 2. details of samples of river water (RW), wastewater (WW) and river sediment (Sed) in the vicinity of the Bobov Dol (CFPP) in Golemo Selo, Bulgaria*

	Sample	Type	Location	Sample description
November 2018	*BG18001***	*RW*	*Razmetanitza river*	*200 m downstream of the sampled discharge point of the black lake ash storage pond*
	BG18002	*Sed*		
	BG18003	*RW*	*Razmetanitza river*	*200 m upstream of the sampled discharge point of the black lake ash storage pond*
	BG18004	*Sed*		
	BG18005	*WW*	*Discharge pipe*	*1 of 2 official discharge points of the black lake ash storage pond to the Razmetanitza river*
March 2019	**Sample**	**Type**	**Location**	**Sample description**
	BG19014	*RW*	*Razmetanitza River*	*200 m upstream of the sampled discharge point of the black lake ash storage pond, as BG18003*
	BG19015	*RW*	*Razmetanitza River*	*200 m downstream of the sampled discharge point of the black lake ash storage pond, as BG18001*
	BG19016	*WW*	*Discharge pipe*	*1 of 2 official discharge points of the black lake ash storage pond to Razmetanitza River, as BG18005*

**For GPS locations of the points of sampling please consult the Technical Report. **Broken bottle, unable to analyse.*

Results for water samples

The water samples collected from the Razmetanitza River upstream of the official discharge points of the black lake in November 2018 (BG18003) and March 2019 (BG19014), contained concentrations of metals and metalloids within the ranges typical for uncontaminated surface waters[37].

The wastewater samples collected from the official discharge point of the black lake (BG18005 in November 2018 and BG19016 in March 2019) also had a similar composition to the upstream river water samples, though with slightly higher dissolved concentrations of a few metals. The results indicate that the upstream discharge was not having a notable impact on water quality in the Razmetanitza River at these times. Unfortunately, it was not possible to sample the second discharge point.

In contrast, the river water sample (BG19015) collected from the Razmetanitza River downstream of both black lake discharge points in March 2019 contained many dissolved metals/metalloids at higher concentrations compared to river water collected upstream (BG19014) on the same day. Concentrations of molybdenum, manganese and vanadium, as well as aluminium, arsenic, boron and calcium, were particularly elevated. This pattern of elevation was similar to that found in the wastewater samples (BG18006 & BG19001) collected from the lower equalizer facility below the final ash disposal site of Kamenik *(for details see The case of the final ash-disposal site Kamenik)*.

These results suggest that wastes from the Bobov Dol CFPP and/or its associated black lake ash storage site are impacting on the water quality of the Razmetanitza River. Furthermore, it seems likely that the second discharge point is the source of such contamination, though unfortunately it was not possible to confirm this inference directly.

Boron

Boron is a naturally occurring metalloid and is present as a trace element in coal, commonly at concentrations in the range 5-100 mg/kg, though some coals contain concentrations of 100's mg/kg[58, 59]. Boron can be released to the atmosphere in gaseous form during coal combustion[60], and is also present within generated fly ash, from which it can readily leach[61, 62, 63]. Boron in the environment is predominantly present as borates, and concentrations of boron in uncontaminated surface waters are generally below 100 µg/l[64, 65, 66]. Average concentrations in uncontaminated soils and sediments are typically around 30 mg/kg, though concentrations can vary considerably with local geology and values up to 100 mg/kg have been reported[67, 68, 69].

Boron can exert toxic effects on aquatic ecosystems when present at concentrations above 1000 µg/l[70]. In humans, boron is an essential nutrient in small amounts but can have toxic effects in higher doses, though only following ingestion in large amounts (10's of grams) with gastrointestinal disturbances being the most common effect[71]. A range of effects have been shown in animal studies, most commonly impacts on male reproduction, though again these relate to ingestion in large amounts, far higher than normal exposure levels[72]. The drinking water limit for boron in the EU is 1000 µg/l[73] and the World Health Organisation (WHO) sets a guideline value for drinking water of 2400 µg/l[74].

Table 3. Concentrations of dissolved metals and metalloids in (F)iltered, and of total metal and metalloid concentrations in (W)hole, unfiltered, water samples (g/l)

Sample year	November 2018				March 2019					
Sample code	BG18003		BG18005		BG19014		BG19015		BG19016	
Place	Razmetanitza, upstream of discharge		Discharge from Black Lake		Razmetanitza, upstream of discharge		Razmetanitza, down of discharges		Discharge pipe	
	F	W	F	W	F	W	F	W	F	W
Aluminium	<5	778	32	210	<5	598	141	3750	24	4175
Antimony	<0.1	<0.1	<0.1	<0.1	0.1	0.3	0.8	0.9	0.1	0.3
Arsenic	1.9	2.3	0.7	0.7	1.6	2.0	8.7	12.1	1.9	4.0
Barium	39.1	46.4	24.3	28.3	33.3	44.6	45.7	87.4	23.0	63.1
Boron	76.8	81.0	13.8	13.8	52.6	59.0	173	197	13.2	20.0
Cadmium	<0.05	<0.05	<0.05	<0.05	<0.05	0.17	<0.05	0.06	<0.05	0.12
Calcium	8920	9140	4735	4850	7280	8260	38500	41300	4375	4930
Chromium total	<0.05	1.66	0.14	1.05	<0.1	1.5	1.1	5.2	0.3	5.3
Chromium (VI)	<20	-	<20	-	<50	-	<20	-	<20	-
Cobalt	0.06	0.26	0.05	0.12	<0.1	0.5	<0.1	0.9	<0.1	1.3
Copper	1.4	3.5	4.8	8.7	1.2	3.5	1.5	6.6	4.3	17.8
Gallium	<0.2	0.2	<0.2	<0.2	<0.2	0.3	0.9	2.1	<0.2	1.4
Iron	9	531	37	258	10	514	7	2380	21	3550
Lead	<0.1	1.3	<0.1	1.1	0.6	1.2	0.1	2.9	0.4	4.3
Manganese	<0.2	71.6	<0.2	7.2	0.3	269	4.9	172	0.4	60.8
Mercury	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum	2.5	2.9	3.0	3.1	1.9	2.3	21.4	21.1	1.3	1.5
Nickel	1.6	2.6	0.5	1.2	1.7	2.9	1.2	6.1	0.9	6.5
Potassium	7150	7490	1890	1950	5250	6360	4650	6830	1915	2680
Rubidium	2.7	4.1	1.1	1.3	2.6	3.8	5.3	9.7	1.2	5.9
Strontium	818	825	169	172	574	585	614	650	130	148
Thallium	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
Uranium	4.41	4.37	1.13	1.12	3.75	3.76	1.81	2.18	1.21	1.62
Vanadium	0.81	1.98	1.42	1.78	0.7	2.1	42.9	55.5	2.7	13.1
Zinc	1.1	6.9	1.2	6.1	<2	13	<2	18	5	38
pH	-	7.7	-	8.2	-	6.7	-	7.5	-	7.5

Results for sediment samples

Concentrations of some metals/metalloids in the Razmetanitza River sediment sample collected downstream from the power plant in 2018 (BG18002) were higher than those in the upstream river sediment (BG18004), most notably for calcium and strontium, as well arsenic, boron, uranium and vanadium. These results suggest accumulation of metals/metalloids in the river sediment due to ongoing releases over time via the second, downstream, discharge point and also possibly via the upstream discharge point at other times.

Table 4. Concentrations of metals and metalloids (mg/kg dry weight) in sediment samples

Sample year	***2018***	
Sample code	***BG1800***	***BG18002***
Location	***Razmetan-itza, upstream of discharges***	***Razmetan-itza, downstream of discharges***
Aluminium	27150	29200
Antimony	<0.05	<0.05
Arsenic	18.0	***38.6***
Barium	225	327
Boron	21.4	***35.9***
Cadmium	0.21	0.22
Calcium	2035	***23100***
Chromium	31.1	35.4
Cobalt	9.5	7.9
Copper	28.6	39.7
Gallium	11.5	13.0
Iron	26400	28300
Lead	22.0	16.1
Manganese	2015	1270
Mercury	<0.1	0.2
Molybdenum	0.7	1.1
Nickel	24.8	35.7
Potassium	4705	3780
Rubidium	24.9	20.8
Strontium	65	***207***
Thallium	0.4	0.4
Uranium	1.97	***3.80***
Vanadium	42.2	***83.5***
Zinc	90	64

Arsenic

Arsenic is a naturally occurring metalloid. The arsenic content of coal can vary considerably between different coal sources, both in terms of the concentration of arsenic and also the form in which arsenic is present. Concentrations are typically in the range 1 – 19 mg/kg[38], though some lignite and brown coals can contain relatively high arsenic content, with concentrations of 100's mg/kg[39]. When coal is burned, arsenic present in the coal is released either to the atmosphere or released within fly ash, depending on the coal type and conditions used[40]. arsenic present in the coal is released either to the atmosphere or released within fly ash, depending on the coal type and conditions used[40].

In the environment concentrations of arsenic in uncontaminated surface are typically below 5 µg/l[41, 42, 43] and concentrations in uncontaminated sediments are usually below 10 mg/Kg, but can vary widely between locations[44]. In surface water, arsenic is present predominantly as arsenate (As^{IV}).

For humans, the main route of exposure for the general population is via food or drinking water[45, 46]. Arsenic compounds in water are rapidly absorbed when ingested[47]. Usually food is the largest source of arsenic.

Seafood is a predominant source, though arsenic in fish and shellfish is mainly present in an organic form called arsenobetaine that is much less harmful[48].

Arsenic is both an acute and chronic toxicant. The toxicity is affected by the oxidation state of arsenic, with As^{III} being more toxic than As^{IV}, as well as its chemical form[49]. Freshwater ecosystems can be impacted by arsenic toxicity, including effects on fish and aquatic mammals[50]. In humans, acute arsenic intoxication is generally associated with ingestion of water containing high concentrations of arsenic and the toxicity is greatly influenced by the rate of removal from the body which can vary between individuals[51]. Chronic effects due to long term exposure via contaminated drinking water include skin lesions, damage to nerves and effects on the cardiovascular system[52]. Of greater concern, however, is the increased risk of carcinogenicity through prolonged ingestion of inorganic arsenic which can result in skin, bladder, liver or lung cancers[53]. Inorganic arsenic compounds are classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC)[54]. Increased risks of lung and bladder cancer, as well as skin lesions, can occur even at concentrations below 50 µg/l[55]. The drinking water limit for arsenic in the EU is 10 µg/l[56], the same value as the WHO provisional guideline value[57].

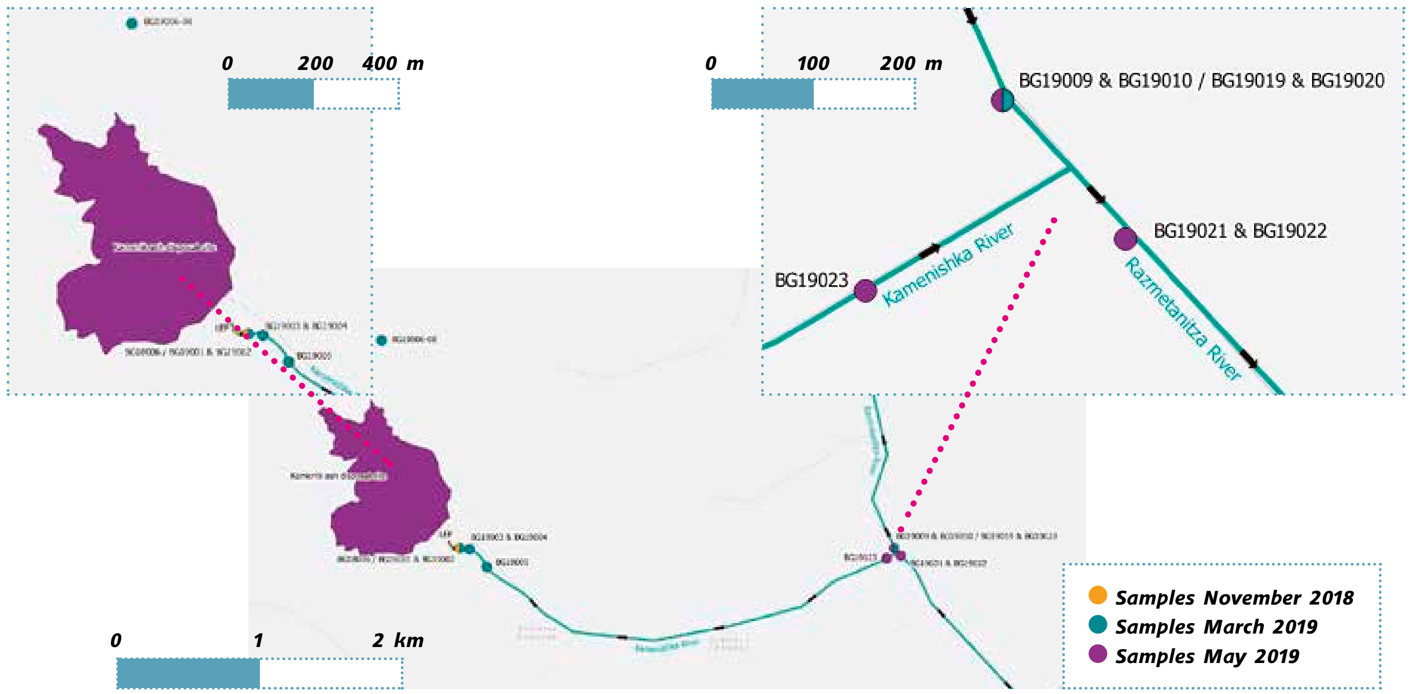
The case of the final ash-disposal site Kamenik

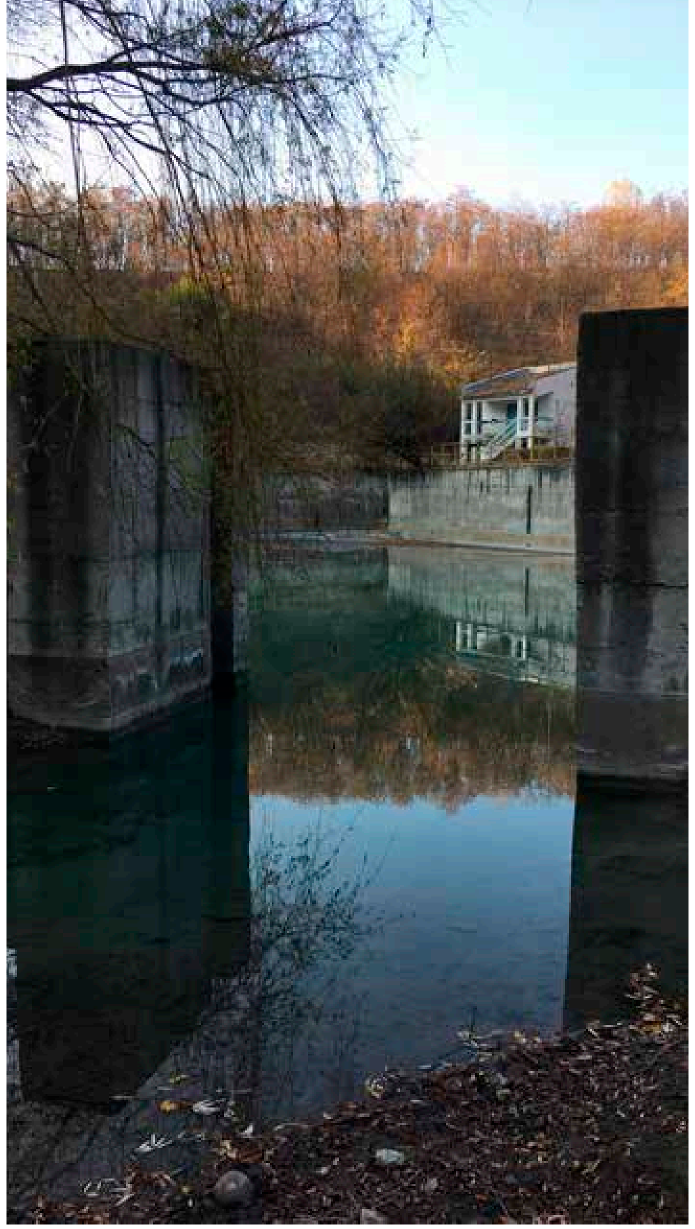
The facility Kamenik, named after the nearby village, is a dam-like construction which receives the ashes left from the operational cycle of the Bobov dol CFPP. The coal waste is considered neutralized through the deposition in the facility. Functioning since 1997 with a projected capacity of 43 000 000 tons, it received a new Integrated Permit in the beginning of 201975, allowing the building of another six 5-meter sections on the dike of the facility and provide for another 27 000 000 tons of the projected capacity[76]. By the end of 2018 over 16 million tons of coal waste have been deposited in Kamenik. The new permit also reflects the introduction of new fuels - biomass and waste, into the operations of the Bobov dol CFPP leading to the disposal of ashes resulting from diverse co-incineration processes[77].

Located below the dike of Kamenik is the "lower equalizer facility (LEF)", as described in the application for a new operational permit for the ash disposal site[78] and its annual environmental reports[79]. According to the documents, the LEF serves as a collector of the water gathered on the territory of the ash disposal site. It is specified that the flows of filtered waste waters and rainwater stay separate at all times. The wastewater supposedly flows into a closed operational cycle which transfers it through a 12-km-long gravity-fed pipeline[80] to a pumping station situated at the black lake, from where it is said to be reused in the industrial water cycle of the Bobov dol CFPP. Only the rainwater, collected through a separate drainage system, is discharged into the Kamenishka River.

In contradiction to the description above, at the time of the sampling visits to the LEF, what appeared to be wastewater was flowing into a water storage area which was not fully contained *(Figure 4)*, and some of this wastewater was observed to be overflowing from the storage area into a concrete channel which is the origin of the Kamenishka River and which flows to the Razmetanitza River near the village of Gramade. This was observed shortly before and shortly after the facility received a new Integrated Permit in January 2019, obviously breaching the prohibition of discharge of industrial waste water into any water body or canalization system[81]. What is more, the new permit was granted without an Environmental Impact Assessment (EIA) which was deemed unnecessary in a screening decision by the competent RIEW-Pernik earlier in 2018[82].

Figure 3. Map of locations of collection of samples near the final ash disposal site of Kamenik





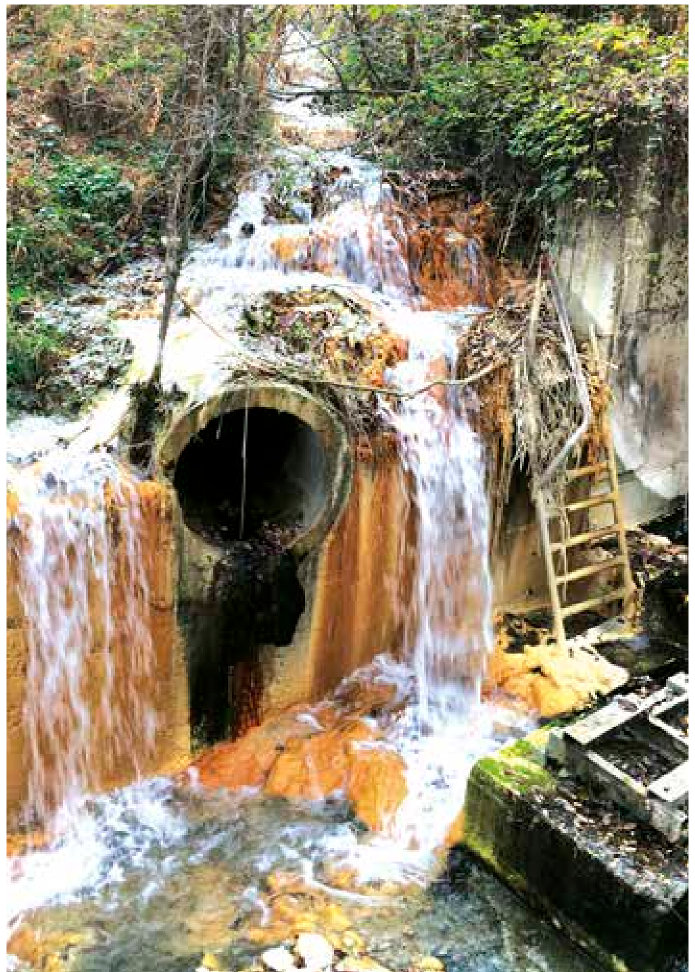


Figure 4. Above & below. Uncontained water at the lower equalizer facility, and overflow of water from the storage area into a concrete channel

Samples

In November 2018 a water sample (BG18006) was collected from the water overflowing from the facility, at the point where it enters the concrete channel. In March 2019 another water sample was collected from the same location (BG19001), together with a sediment sample from below the water flow at this location (BG19002) *(Figure 5)*.

A short distance downstream from the overflow sampling location, the concrete channel section of the Kamenishka river flows underground, below a road, before flowing through another small channel *(Figure 6)* and joining the Razmetanitza river approximately 3.5 km from the underground section, and approximately 10 km downstream from the CFPP. In March 2019, a water sample (BG19003) and an associated sediment (BG19004) were collected from the channel immediately after it re-emerges from under the road, together with a sediment (BG19005) from the channel further downstream.

Figure 5. Collecting a sample from the sediment below the water overflowing the LEF

Figure 6: Concrete channel downstream of the lower equalizer facility as it re-emerges after flowing underneath the road, and small channel further downstream

Table 5. details of samples of river water (RW), wastewater (WW) and river sediment (Sed) collected in the vicinity of the Kamenik ash disposal site of the Bobov Dol CFPP in Golemo Selo, Bulgaria*

November 2018	Sample	Type	Location	Sample description
	BG18006	WW	LEF	Facility immediately below the dike of the Kamenik ash disposal site. Water flows into a storage area, which overflows into a concrete channel which becomes the Kamenishka River. Sample collected at the entry point of the water into the channel.
March 2019	**Sample**	**Type**	**Location**	**Sample description**
	BG19001	WW	LEF overflow	Point where wastewater enters the channel, after overflowing from the LEF area. Same as BG18006
	BG19002	Sed		
	BG19003	WW	Downstream of LEF	Concrete channel downstream from where BG19001/02 were collected, immediately after the channel flows underground for a short distance, below a road.
	BG19004	Sed		
	BG19005	Sed	Further downstream of LEF	Small channel into which the concrete channel flows, and later becomes the Kamenishka River. Wastewater not collected at this location: there are no visible water inputs to the channel between BG19003/04 and this location

Results for water samples

The sample of wastewater (BG18006) collected in November 2018 below the LEF had a very different composition to local surface water, as represented by river water from the Razmetanitza River collected upstream of the CFPP and black lake ash storage site (BG18003). The LEF wastewater contained far higher concentrations of many metals and metalloids in dissolved forms, especially molybdenum at almost 500 times higher, gallium and rubidium at approximately 100 times higher, and many others at 5-10 times their respective river water concentrations. Though lower than most other metal/metalloids, the concentration of dissolved mercury in the wastewater (1.0 µg/l) was higher than environmental quality standards (EQS) for inland waters in the EU[83], which includes a maximum allowable EQS of 0.07 µg/l (and an annual average EQS of 0.05 µg/l). Fly ash from the Bobov Dol CFPP is reported to contain traces of mercury, at around half the average concentration reported for coal fly ashes but in a relatively mobile form[84].

**For GPS locations of the points of sampling please consult the Technical Report.*

Similar concentrations of metals and metalloids to those in the 2018 sample (BG18006) were found in the samples collected in March 2019 from the same location and two others further downstream. This indicates that the channel which re-emerges from underground is the same channel into which the LEF overflows, and that there are no significant additional inputs of water to the portion of this channel within the underground section.

The metals and metalloids found in higher concentrations in the LEF wastewater are elements known to leach from coal fly ash, though numerous other sources also exist[85, 86]. Molybdenum and boron readily leach from coal fly ash, which is also a known source of gallium[87, 88], though the amount and rate of leaching from the ash is dependent on the individual metal/metalloid, and can also vary considerably between fly ash from different types of coal[89, 90].

Table 6. Concentrations of dissolved metals and metalloids in (F)iltered and of total metal and metalloid concentrations in (W)hole, unfiltered, water samples (µg/l)

Sample year	2018				March 2019			
Sample code	BG18006		BG19001		BG19003		BG19009	
Location	Overflow from LEF		Overflow from LEF		Downstream of LEF		Razmetanitza upstream of Kamenishka	
	F	W	F	F	F	W	F	W
Aluminium	222	283	136	208	160	219	63	1210
Antimony	0.4	0.4	0.6	0.5	0.5	0.5	0.9	0.9
Arsenic	27.8	28.4	29.5	29.5	29.5	29.4	10.6	13.1
Barium	49.0	51.0	44.4	48.2	46.3	50.6	62.1	80.3
Boron	345	337	298	326	304	334	239	252
Cadmium	0.12	0.15	0.13	0.15	0.13	0.17	<0.05	<0.05
Calcium	41000	41400	41300	41400	43400	44600	29000	30000
Chromium total	<0.05	0.23	0.7	0.9	0.6	0.8	0.8	2.5
Chromium (VI)	<20	-	<20	-	<20	-	<20	-
Cobalt	0.05	0.06	<0.1	<0.1	<0.1	<0.1	<0.1	0.5
Copper	0.5	1.3	0.6	1.9	0.5	1.9	1.2	4.1
Gallium	17.5	17.6	15.5	15.9	13.5	13.9	0.6	1.1
Iron	<5	43	<5	<5	<5	7	12	890
Lead	0.2	0.6	0.3	0.5	0.2	0.7	0.4	2.0
Manganese	39.1	44.8	51.0	51.7	56.5	57.5	12.0	293
Mercury	1.0	1.1	1.1	1.1	1.0	1.0	<0.2	<0.2
Molybdenum	1170	1155	1070	1120	1020	1040	23.9	23.6
Nickel	0.4	1.1	<0.5	1.0	<0.5	1.7	1.0	3.4
Potassium	111000	114000	101000	104000	99300	101000	6250	7070
Rubidium	279	280	252	249	227	225	4.7	5.8
Strontium	3660	3685	2810	2850	2950	2990	823	813
Thallium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Uranium	0.49	0.48	0.74	0.73	0.95	0.93	5.19	5.16
Vanadium	15.5	15.5	13.6	14.3	12.1	12.6	38.6	47.6
Zinc	0.6	3.1	<2	9	<2	8	4	12
pH	-	-	-	6.9	-	6.9	-	6.8

Results for sediment samples

Sediment collected from the location at which wastewater overflows from the LEF water storage area into the concrete channel at the head of the Kamenishka River (BG19002) contained a number of metals/metalloids at elevated concentrations, higher than those recorded in the sediment samples from the Razmetanitza River - both upstream of the black lake ash storage discharges (BG18004) and immediately upstream of its confluence with the Kamenishka river (BG19010).

The concentrations of calcium and strontium were particularly elevated over those in the Razmetanitza River sediments, as were those of arsenic, molybdenum and to a lesser extent boron and manganese. Sediment in the two samples of solid material (BG19004 and BG19005), collected from locations further downstream in the same channel, contained similar or lower concentrations of all metals and metalloids compared to that collected directly below the LEF outflow (BG19002).

Although differences exist in the composition of sediment along the Kamenishka River, all sediment samples showed elevated concentrations of metals and metalloids present in wastewaters discharged from the LEF compared to sediment from the Razmetanitza River upstream of the CFPP and ash disposal sites.

Though over 20 years old, previously reported data for waste streams from the Bobov Dol CFPP also showed relatively high concentrations of many of these metals and metalloids in pond wastewater, including arsenic, boron, manganese, vanadium and calcium at even higher concentrations than those in the LEF wastewater samples from this study[91]. Molybdenum, strontium and potassium concentrations were also reported to be high in pond water relative to surface waters at that time, though concentrations found in LEF wastewater in our study (BG18006 and BG19001) were even higher. It is not known whether the pond water from that study was collected from any of the locations from which samples were collected for the current study.

Despite the obviously ongoing releases of wastewater from the LEF of Kamenik, proven by the results of these samples, the competent authorities have not put in place any measures to monitor the quality of the surface water: in the application for a new permit the operator declares there would not be any discharges of wastewater in the environment and therefore the permit itself does not contain any conditions for monitoring the quality of the local surface water[92]. Furthermore, the monitoring of groundwater and soil which is conditioned in the permit, is based on samples from locations above the ash disposal site, and on the left and right slopes around the dike, all above the LEF[93]. In this way, the pollution from long-term coal ash storage remains under the radar, with the environment bearing all the costs.

Figure 7. The concrete channel leading out of the LEF along the Kamenishka river

Table 7. Concentrations of metals and metalloids (mg/kg dry weight) in sediment samples

Sample year	**November 2018**		**March 2019**		
Sample code	**BG18004**	**BG18002**	**BG19002**	**BG19004**	**BG19005**
Location	**Razmetan-itza, upstream of discharges**	**Razmetan-itza, downstream of discharges**	**Overflow from LEF**	**Downstream of LEF**	**Further downstream of LEF**
Aluminium	27150	29200	11300	2350	6240
Antimony	<0.05	<0.05	0.08	<0.04	0.04
Arsenic	18.0	38.6	149	99.7	77.0
Barium	225	327	192	152	148
Boron	21.4	35.9	29.3	25.4	16.6
Cadmium	0.21	0.22	0.07	<0.02	0.04
Calcium	2035	23100	41800	49600	32900
Chromium	31.1	35.4	9.02	1.52	14.3
Cobalt	9.5	7.9	2.30	0.37	2.05
Copper	28.6	39.7	5.3	1.5	5.3
Gallium	11.5	13.0	14.1	18.8	17.2
Iron	26400	28300	6000	889	8510
Lead	22.0	16.1	4.48	0.93	3.03
Manganese	2015	1270	1260	651	620
Mercury	<0.1	0.2	<0.1	<0.1	0.12
Molybdenum	0.7	1.1	4.00	4.43	3.61
Nickel	24.8	35.7	7.7	1.3	6.4
Potassium	4705	3780	2220	544	1140
Rubidium	24.9	20.8	17.0	2.3	8.3
Strontium	65	207	1050	1170	666
Thallium	0.4	0.4	0.11	<0.04	0.05
Uranium	1.97	3.80	2.17	2.81	2.15
Vanadium	42.2	83.5	18.7	16.4	23.2
Zinc	90	64	16	4	12

Mercury

Mercury is a naturally occurring metal, and mercury compounds are present as trace components in coal. Concentrations of mercury in coal are typically in the range 0.01-1 mg/kg, though some contain up to 10 mg/kg[110, 111]. Coal burning constitutes the main source of mercury emissions to the environment from human activities[112].

Mercury is released when coal is burned, predominantly to the atmosphere though also within fly ash. Releases to the atmosphere are affected by the type of coal and the burning conditions, and can be reduced by pollution control devices, especially wet flue gas desulfurisation (FGD)[113, 114]. Mercury is emitted to the flue gases in two predominant forms: elemental mercury and gaseous oxidised mercury, which is also referred to as reactive gaseous mercury (RGM). Wet FGD reduces atmospheric emissions of oxidised mercury but does not normally capture elemental mercury[115]. Following release to the atmosphere, elemental mercury can travel globally and impact far from the source of its release[116].

Mercury is found naturally in the environment, though generally at extremely low concentrations. Levels in uncontaminated river sediments can vary, but concentrations are typically below 0.4 mg/kg[117]. Surface freshwaters without known sources of mercury contamination generally contain less than 1 ng/l (0.001 μg/l) of total mercury[118].

Mercury can exist in a number of forms: metallic mercury (including mercury vapour), inorganic mercury compounds and organic mercury compounds. The toxicity of mercury is dependent on the form[119]. Following release to the aquatic environment, mercury can become transformed into methyl mercury, a highly toxic organic mercury form that can bioaccumulate and biomagnify (progressively concentrate) to high levels in food chains, particularly in fish[120]. Methylation of inorganic mercury has been shown to occur in freshwater environments[121].

For humans, food is the main source of mercury exposure in general populations, predominantly in the form of methyl-mercury[122, 123, 124]. This form of mercury can accumulate in the body and its main impact is damage to the nervous system. Methyl-mercury can readily pass through the placental barrier and the blood-brain barrier, and can have adverse effects on the developing brain and central nervous system in foetuses and children, including a lowering of IQ, even at levels to which many people are currently exposed in some countries[125, 126, 127]. Research also indicates that exposure can increase cardiovascular and heart disease[128].

Mercury and its compounds have been listed as priority hazardous substances under the European Water Framework Directive[129], and as a result Environmental Quality Standards (EQS) for inland waters in the EU include a maximum allowable concentration of 0.07 μg/l for mercury, and a maximum annual average of 0.05 μg/l[130]. The drinking water limit for mercury in the EU is 1 μg/l[131], and the WHO sets a guideline value of 6 μg/l for inorganic mercury[132].

Molybdenum

Molybdenum is a naturally occurring metal which is present as a trace element in coal, commonly at concentrations in the range 1-10 mg/kg, though some coals contain concentrations up to 300 mg/kg[94, 95]. Following combustion of coal, the majority of the molybdenum is transferred to fly ash, from which it can readily leach[96, 97].

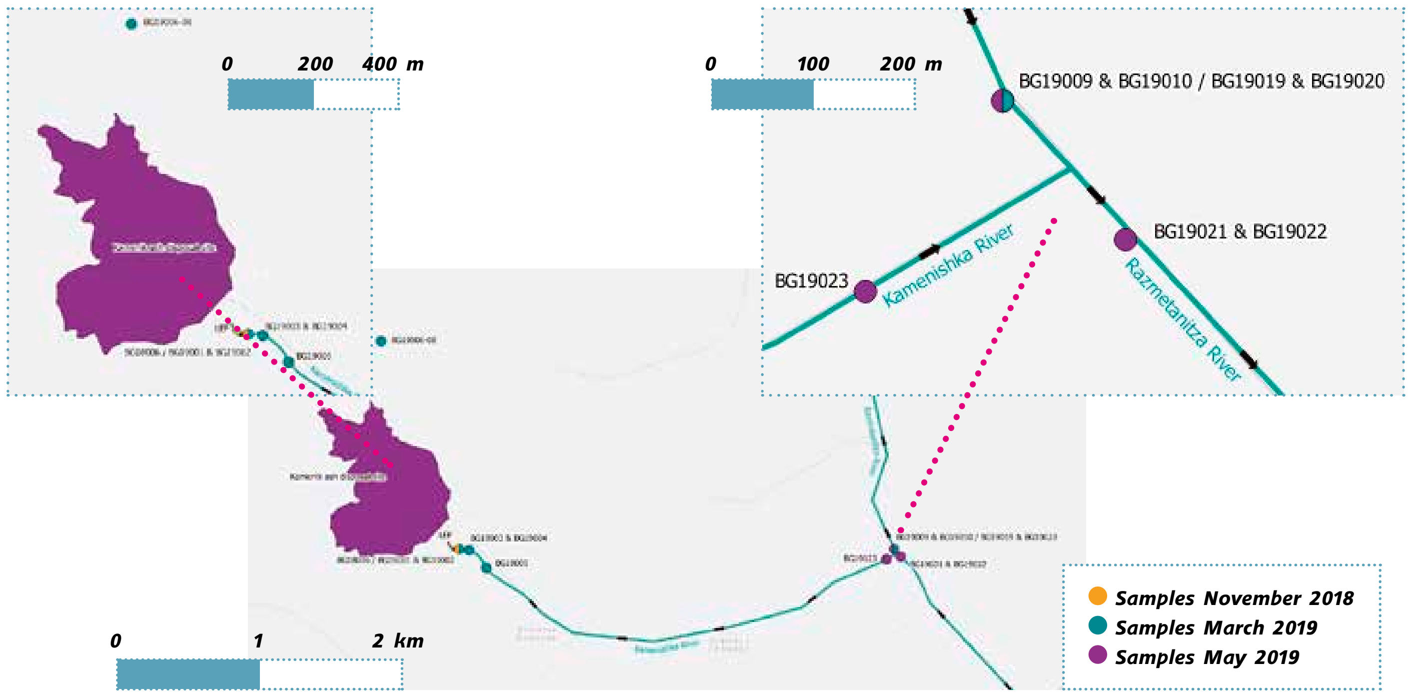
Concentrations of molybdenum in uncontaminated surface waters are generally below 10 μg/l and often far lower. The median concentration in European surface waters is 0.22 μg/l[98, 99, 100]. Average concentrations in uncontaminated soils and sediments are typically below 10 mg/kg[101, 102].

Molybdenum is considered to be an essential micro-nutrient, and some molybdenum compounds are used as food supplements. For humans, harmful effects due to ingestion only occur following very high doses[103, 104, 105]. Soluble molybdenum oxide salts (molybdates) can be toxic to freshwater aquatic organisms, though again only at very high concentrations, generally over 100 mg/l (100000 μg/l)[106].

The WHO advises a health-based value of 70 μg/l molybdenum in drinking water, though the previously set guideline value of 70 μg/l is no longer used as WHO consider that concentrations above that level are rarely found in drinking water[107]. No drinking water limit for molybdenum has been set by the EU[108], though a national limit does apply in some parts of the EU; Denmark, for example, sets a drinking water limit of 20 μg/l molybdenum[109].

The case of the confluence

Figure 8. Map of locations of collection of samples near the confluence of the Kamenishka and Razmetanitza rivers



Samples

In March 2019, a sample of river water (BG19009) and another of sediment (BG19010) were collected from the Razmetanitza river immediately upstream of its confluence with the Kamenishka river. During the sampling visits the Kamenishka River flowed through a swampy area for a short distance prior to joining the Razmetanitza River, and at the confluence there was no visible water flow above ground.

This area was revisited in May 2019 and another set of river water (BG19019) and associated sediment (BG19020) samples were collected from the same location. On that occasion, a sample of river water (BG19023) was also collected from the Kamenishka River, approximately 40 m upstream of the same confluence, and before the Kamenishka flows through the swampy area. In addition, a further set of river water (BG19021) and associated sediment (BG19022) samples were collected from the two combined river water flows *(still known as the Razmetanitza river)*, immediately downstream of their confluence.

The water sample (BG19009) collected from the Razmetanitza River in March 2019 immediately upstream of the confluence with the Kamenishka River generally contained dissolved metal/metalloid concentrations which were similar to, or slightly lower than, those found in water sample BG19015, collected just below the two black lake discharge points. A second sample collected from the same location in May 2019 (BG19019) contained similar or slightly higher concentrations.

Similarly, and as may be expected, a sample of water (BG19023) collected from the Kamenishka River just before it joins the Razmetanitza River contained a similar composition of key metals and metalloids to the water samples collected upstream within this channel, closer to the LEF (BG18006, BG19001, BG19003).

Table 8[133]. details of samples of river water (RW), wastewater (WW), river sediment (Sed) and ash collected in the vicinity of the Kamenik ash disposal site of the Bobov Dol CFPP

March 2019	**Sample**	**Type**	**Location**	**Sample description**
	BG19006	**WW**	*Kamenik ash disposal site*	*Concrete channel that usually transports ash slurry from a conveyor belt to a pipe which deposits ash at the Kamenik ash disposal site. At time of sampling (11th March) only water flowed through the channel, and the flow rate was lower than previously observed.*
	BG19007	**Solid, ash?**	*Kamenik ash disposal site*	*Solid material built up on sides of the concrete channel. Collected on 11th March at same location as BG19006*
	BG19008	**Ash slurry**	*Kamenik ash disposal site*	*Sampled from the same channel as BG19006, on a different day (13th March), approx. 150m downstream of BG19006. Steady flow of slurry observed along the channel at this time.*
	BG19009	**RW**	*Razmetanitza River upstream of Kamenishka*	*Approx. 10 km downstream from the Bobov Dol CFPP, about 10 m upstream of the confluence with the Kamenishka river (the continuation of the LEF concrete channel flow)*
	BG19010	**Sed**		
May 2019	**Sample**	**Type**	**Location**	**Sample description**
	BG19019	**RW**	*Razmetanitza river upstream of Kamenishka*	*Approx 10 m upstream of confluence with the Kamenishka River (same as BG19009; BG19010)*
	BG19020	**Sed**		
	BG19021	**RW**	*Razmetanitza river downstream of Kamenishka*	*Approx. 20 m downstream of confluence with the Kamenishka River*
	BG19022	**Sed**		
	BG19023	**RW**	*Kamenishka river*	*Approx. 40 m upstream of confluence with Razmetanitza River*

The water sample from the two combined river water flows *(still known as the Razmetanitza River)*, collected immediately downstream of their confluence (BG19021), had a very similar composition to that of the Razmetanitza River water collected upstream of the confluence on the same day (BG19019), despite the mixing of the two rivers, probably as a result of the much higher flow-rates in the Razmetanitza compared to the Kamenishka. Nonetheless, the presence of high metal concentrations in the Kamenishka River confirms that wastewaters flowing from the ash disposal site and overflowing from the LEF are a significant additional source of environmental contamination to the river system.

The case of coal ash in the river water

Figure 9. Razmetanitza River upstream of the confluence with the Kamenishka River; (a) March 2019, (b) May 2019

During the visit to the site in May 2019, the water flowing in the Razmetanitza River was observed to be saturated with vast amounts of solid material. It was opaque and dark grey in colour, markedly different to the appearance in March when the river water was far more transparent and appeared to contain far less suspended solids ***(Figure 9)***. This was also observed to be the case at a location further upstream towards the power plant, approximately 1.5 km below the discharges from the black lake ash storage site. Incidentally, both whole (unfiltered) river water samples collected from the Razmetanitza River in May (BG19019 & BG19021) contained far higher concentrations of all metals and metalloids compared to the water sample collected in March 2019 (BG19009), as expected from the far higher loading of suspended solids in the river water in May.

Comparison of these suspended solids samples with sediment collected from the Razmetanitza River in March 2019, when the river water was far less turbid, indicates that the suspended solids in May 2019 were very different in composition to that of the river sediment, most notably for boron, calcium, molybdenum, strontium, uranium and vanadium.

Parallel with ash slurry

In light of the visibly different nature of the Razmetanitza River water in May 2019, compared to March 2019, suspended solids filtered out from the May 2019 river water samples (BG19019SS and BG19021SS) were also analysed, to enable comparison with samples of ash collected in March.

The suspended solids (BG19019SS and BG19021SS) contained a very similar composition to each other in terms of metal and metalloid concentrations.

To enable the comparison with ash, samples were collected from a concrete channel close to the Kamenik ash disposal site. This channel is used to transport ash, delivered from the black lake via a conveyor belt and then mixed with water, to a pipe which pours it into the Kamenik ash disposal site. Amongst these, a sample of ash slurry (BG19008) was collected directly from the channel.

The transportation of coal ash mixed with water through this open concrete channel leads to the material building up on the sides (Figure 10), as indicated by the sample of solid material (BG19007), and occasionally spilling in the surrounding environment (Figure 11). The chemical composition of this solid material (BG19007) was very similar to that of the solids in the ash slurry (BG19008).

Concentrations of key metals/ metalloids in the solids filtered out from the river water samples (BG19019SS and BG19021SS) were very similar to those for the ash collected from the channel (BG19008), indicating that the solid material in the Razmetanitza River water in May 2019 was predominantly ash from the black lake site.

Figure 10. Solid material built up on the sides of the concrete channel used to transport ash slurry, close to the Kamenik ash disposal site

Figure 11: The coal ash slurry transported through the open concrete channel occasionally spills into the surrounding environmen

Figure 12: The sample of coal ash slurry (BG19008, 13th March 2019), which was very alkaline (pH=12.7)

Results for Water Samples

Table 9. Concentrations of dissolved metals and metalloids in (F)iltered and of total metal and metalloid concentrations in (W)hole, unfiltered, water samples (µg/l)

Sample year	May 2019					
Sample code	BG19019		BG19021		BG19023	
Location	Razmetanitza upstream of Kamenishka		Razmetanitza downstream of Kamenishka		Kamenishka	
	F	W	F	W	F	W
Aluminium	124	216000	126	168000	32	2200
Antimony	2.6	8.3	2.7	6.7	0.4	0.6
Arsenic	42.0	321	43.1	282	23.6	24.5
Barium	74.6	1980	67.9	1670	67.3	84.8
Boron	312	587	277	614	321	327
Cadmium	0.10	3.02	<0.05	1.73	0.18	0.16
Calcium	64900	148000	56700	127000	46300	46950
Chromium total	1.6	286	1.5	215	0.3	3.2
Chromium (VI)	<20	-	<20	-	<20	-
Cobalt	<0.1	53.4	<0.1	44.0	<0.1	0.8
Copper	1.6	274	1.4	220	2.9	7.1
Gallium	1.1	67.4	1.1	55.5	7.6	9.8
Iron	6	141000	7	117000	<5	1695
Lead	0.2	139	0.1	119	0.4	1.8
Manganese	35.3	1680	30.8	1400	11.6	65.4
Mercury	0.2	2.0	0.3	1.7	0.5	0.5
Molybdenum	26.5	47.1	26.1	41.6	972	936
Nickel	1.2	322	1.1	261	0.8	3.7
Potassium	5970	37100	5970	30500	96150	96550
Rubidium	7.6	254	7.7	197	198	200
Strontium	955	2270	904	2010	3230	3250
Thallium	<0.1	3.5	<0.1	2.9	<0.1	<0.1
Uranium	5.89	43.3	5.66	37.1	4.60	4.80
Vanadium	45.6	877	45.9	723	9.3	13.5
Zinc	<2	432	<2	350	<2	12
pH	-	7.5	-	7.8	-	-

Table 10. Concentrations of metals and metalloids (mg/kg dry weight) in ash, sediment (sed), and river water suspended solids (SS) samples. (a) Typical range of concentrations in fly ash (EPRI 2009); (b) reported concentrations in lagooned ash at the Bobov Dol facility (Vassileva et al. 1997); data from Kostova et al. 2011

Sample year	March 2019			May 2019				Literature		
Sample code	BG 19007	BG 19008	BG 19010	BG 19020	BG 19022	BG 19019 SS	BG 19021 SS	-		
Type	ash	ash	sed	sed	sed	SS	SS	ash		
Location	side of slurry channel	Ash slurry	Razmetan -itza, up-stream of confluence	Razmetan -itza, up-stream of confluence	Razmetan -itza, down-stream of confluence	Razmetan -tza, up-stream of confluence	Razmetan-tza, down-stream of confluence	fly ash, typical[a]	Lagoon ash, Bobov Dol[b]	fly ash, Bobov Dol[b]
Aluminium	47150	44500	20000	29600	41400	42600	41500	70000-140000	-	-
Antimony	0.09	0.18	0.05	<0.1	<0.1	<0.1	<0.1	BDL-16	3.3	3.4
Arsenic	50.2	67.8	18.4	17.2	20.8	38.2	36.0	22-260	45	56
Barium	460	441	198	220	343	337	334	380-5100	650	875
Boron	97.3	117	11.7	24.0	48.0	56.4	55.8	120-1000	-	-
Cadmium	0.27	0.36	0.15	0.14	0.15	0.39	0.23	BDL-3.7	-	-
Calcium	12150	10600	1880	4320	10400	10300	10300	7,400 – 150000	-	-
Chromium	70.2	72.8	29.1	46.0	59.4	65.8	63.6	27-300	110	118
Cobalt	18.1	17.6	9.13	10.3	12.8	12.4	12.2	-	24	25
Copper	39.5	40.5	21.8	28.1	49.6	54.7	52.8	62-220	45	55
Gallium	16.5	16.9	8.7	10.4	12.8	14.2	13.7	-	20	25
Iron	43000	38900	24700	26100	35800	32200	31800	34000-130000	-	-
Lead	20.6	25.0	19.4	14.4	13.1	16.4	16.4	21-230	35	40
Manganese	225	187	570	420	362	291	282	91-700	-	-
Mercury	<0.1	<0.1	<0.1	0.1	0.1	0.4	0.2	0.01-0.51	-	0.035-0.055[c]
Molybdenum	6.56	8.09	0.76	0.92	2.52	3.73	3.52	9.0 – 60	6	7
Nickel	43.7	47.9	27.1	37.8	64.9	71.9	75.4	47-230	90	110
Potassium	4805	4430	2480	4455	5460	5400	5330	6200 – 21000	-	-
Rubidium	51.5	47.8	33.0	35.7	38.6	40.0	38.7	-	175	146
Strontium	368	335	73.1	116	242	234	230	270-3100	400	430
Thallium	0.59	0.70	0.35	0.43	0.44	0.56	0.53	BDL-45	<1	<1
Uranium	5.61	5.69	1.79	3.20	6.14	6.81	6.81	BDL-19	14	10
Vanadium	160	165	45.9	80.1	122	146	143	BDL-360	196	244
Zinc	81	94	69	54.3	59.5	73.7	67.8	63-680	130	155

A Loose Institutional Control

Following the sampling of river water, and the observed turbidness and unnatural grey colour of the water flow, saturated with what appeared to be large amounts of coal ash on 21 May 2019, Greenpeace – Bulgaria signaled the Regional Authority of Environment and Water (RIEW) in Pernik via the dedicated Green phone line. The signal was later backed with pictures sent by email. In a written reply to the signal, RIEW-Pernik described the measures undertaken in response to the alert for a potential unauthorized release of coal ash into the Razmetanitza river. On the day of the signal the authority gathered information by phone and drew the conclusion that the river was turbid because of torrential rains on the previous day. Also by phone, RIEW-Pernik requested information about emergencies in the operational cycle of the Bobov dol CFPP and the operator reported none had occurred in the three days prior to the signal. In the end, the area was not visited, nor was the river water sampled by representatives of the controlling authority.

On a previous similar occasion in November 2017, following a Green phone line signal, RIEW-Pernik conducted checks and established that the Bobov dol CFPP was discharging waste waters into the Razmetanitsa River in breach of its Integrated Permit. The operator received a fine of 3000 leva (a little more than 1500 EUR) which was challenged in court and finally confirmed in the summer of 2018[134].

Additionally, a week prior to the Greenpeace signal, RIEW-Pernik imposed an "ongoing monthly sanction" on the Bobov dol CFPP of 2816 leva/month (1400 EUR/month). It was the result of an emissions control check on the power plant's waste waters, conducted in February 2019. The documents, acquired by Greenpeace – Bulgaria through an Access to Information Request, show that the operator was not abiding by the individual emissions limits set in its Integrated Permit. The content of undissolved substances was more than six times the limit values, the content of iron – more than four times the limit values, and the pH exceeded the upper limit value[135].

These examples show that the sanctions imposed fail to act as a deterrent for future breaches of environmental standards, or to serve as a motive for the operator to avert such instances in the future. Moreover, the institutional capacity proves insufficient to establish effective control, despite similar recent precedent-setting circumstances. On top of that, the history of pollution does not factor in the permitting procedure by the Executive Environment Agency as it should in order to protect the health of people and the environment.

Air

The Bobov Dol CFPP is only a few hundred meters away from the houses in the village of Golemo Selo, which is home to around 400 people. The residents often complain of air pollution - be it black smoke from the high stacks of the facility, or white lime powder covering the area due to sulphur scrubber malfunctions. The site is located within a wide open valley where local topography is unlikely to reduce the potential for pollutant dispersion. As the mix of coal, and more broadly - the mix of fuels, used at the plant is known to vary over time, pollutant emission rates may also change.

The principal sources of atmospheric pollution within the study area are likely to be burning solid fuels, in particular coal burning for domestic heating in Golemo Selo, and for electricity generation at the Bobov Dol CFPP.

In terms of air pollution arising from road traffic, the nearest heavily trafficked road is the A3 highway which is approximately 3 km east of Golemo Selo. Only minor roads pass close to the village and local traffic is therefore likely to be a relatively minor source of air pollution. However, some coal supplied to the CFPP during the period of this study is delivered by roads with trucks passing through Golemo Selo several times per day. While the truck load is covered to prevent emission of dust, these trucks have the potential to generate additional local air pollution through exhaust gases, resuspension and related processes.

Usually, coal is delivered to the CFPP via a freight railway, with trains observed running twice per day. According to local media reports, in the months of the study period the railway has been used for the delivery of refuse-derived fuels (RDF) to the power plant[136]. The railway line, located between Golemo Selo and the power plant, is equipped with electric power lines, driving electric locomotives. The railway itself is therefore also unlikely to be a major source of local air pollution.

Land use in the study area is predominantly agricultural, and may give rise to emissions of particulate matter and associated air pollutants. The Bobov Dol CFPP and associated installations are the single significant industrial presence.

Modelling, based on emissions data from 2016, shows that its pollution results in 21 premature deaths, 465 asthma symptom days in asthmatic children, 10 cases of chronic bronchitis in adults, 16 hospital admissions due to respiratory or cardiovascular symptoms, 5050 work days lost, and a total of 61 000 EUR for health costs per year[137].

Materials and Methods

This report describes the results of a three-month air pollutant monitoring survey carried out at Golemo Selo, near to Bobov Dol CFPP. The analysis is based on four types of data:

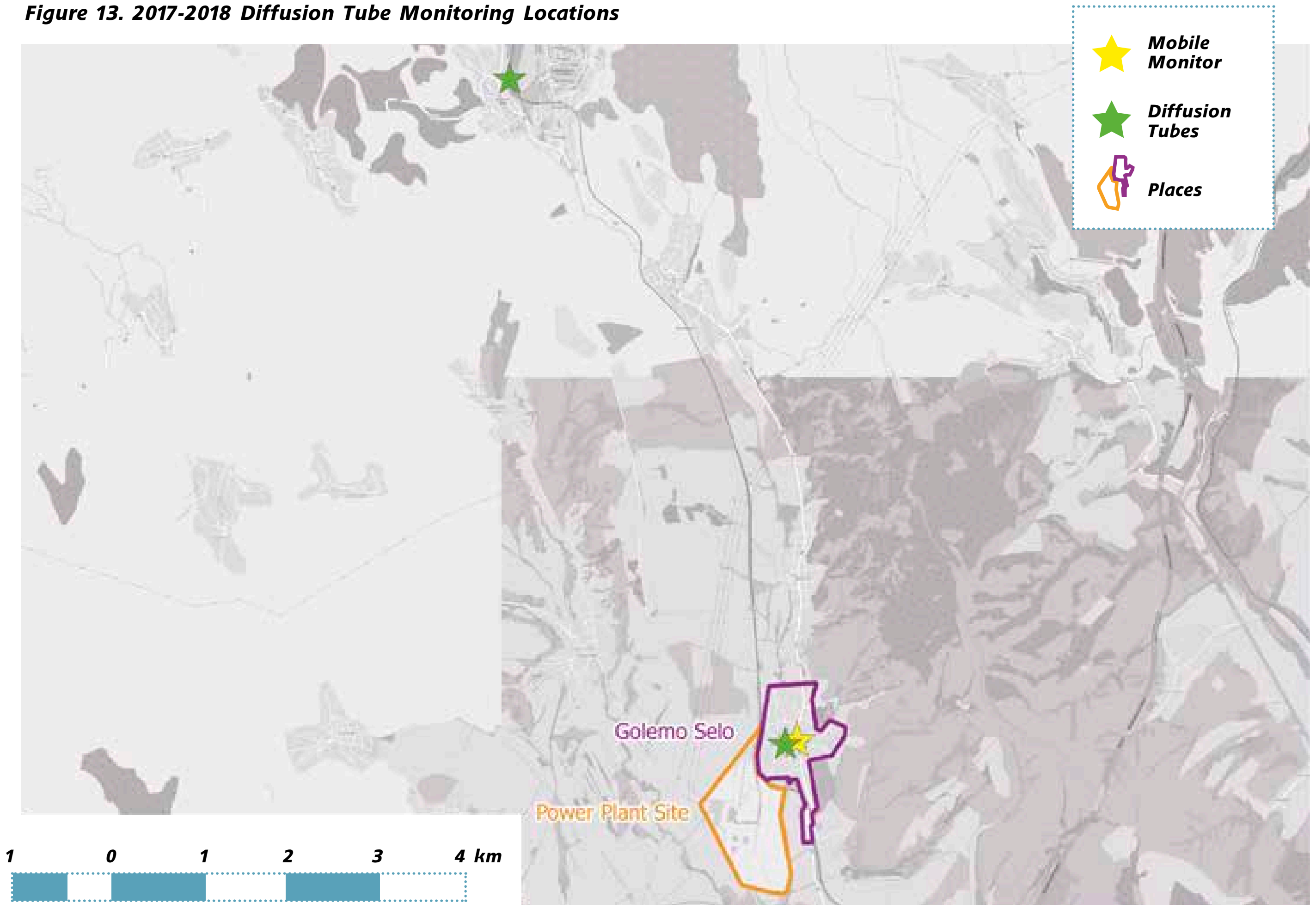
- *The monitoring of ambient air pollutants, including NO, NO_2 and O_3, conducted by Greenpeace - Bulgaria with an AQMesh pod from 21st February 2019 until 22nd May 2019;*
- *The monitoring of PM10 concentrations conducted by Greenpeace - Bulgaria with a pDR machine in several periods between 21st February 2019 and 22nd May 2019;*
- *Results of a diffusion tube monitoring survey, completed in 2018;*
- *Official monitoring of ambient air pollutants, including SO_2, NO_2 and PM_{10}, carried out by the Bulgarian Executive Environment Agency with a mobile monitoring station in the spring of 2019.*

The AQMesh pod and the pDR machine were deployed in a residential area of Golemo Selo. The diffusion tubes were positioned in central locations in Golemo selo and Bobov dol, and the mobile monitoring station of the EEA was positioned in the center of Golemo selo, as shown on ***Figure 13***[138].

CFPPs usually operate continuously, with periodic shutdowns for maintenance. On 17th March, during the study period, the CFPP stopped working due to low electricity prices[139]. It resumed operation at 08:00 on 18th March. It stopped once again for planned repair work on 6th April and resumed operation in the morning of 8th April[140].

The study area considered in this report is defined in ***Figure 13*** and comprises the Bobov Dol CFPP, Golemo Selo and surrounding settlements in Kyustendil Province, western Bulgaria. The area contains residential properties and a kindergarten whose occupants are sensitive to the effects of air pollution.

Figure 13. 2017-2018 Diffusion Tube Monitoring Locations



Mobile monitoring station by EEA

Figure 14. The mobile monitoring station of the Executive Environment Agency

A network of automatic air quality monitoring stations is operated in Bulgaria by the Executive Environment Agency. None of these monitors are located within the study area; however, a mobile monitoring station was placed in the center of Golemo Selo by the EEA during the study. It collected hourly measurements of air pollutants including SO_2, NO, NO_2, O_3 and PM_{10}.

The mobile monitoring station operated for two periods: 15 March 2019 - 29 March 2019, and 23 April 2019 - 11 May 2019.

The results from the official monitoring have been provided by the Executive Environment Agency through an Access to Information Request.

AQMesh

AQMesh pods are self-contained devices that measure ambient concentrations of pollutant gases (including NO, NO_2 and O_3) and operate on battery power. In the study period the AQMesh was positioned at a height of approximately 2 m. Nearby residential properties commonly use coal burning stoves for heating and cooking. The closest residential property to the monitoring location ceased using its stove in mid-April, although others nearby were observed continuing to burn solid fuel after that date.

Figure 15. An AQMesh pod

pDR

The personal DataRAM 1500 (pDR) is a portable particulate matter monitor distributed by Thermo Scientific. The pDR 1500 carefully separates particulate matter according to particle size before a laser is used to measure accurately the mass concentrations of fine particulates in air. The pDR pod was also deployed at the residential location in Golemo Selo. It was located east of the Bobov dol power plant from 21st February 2019 until 22nd May 2019. It was positioned at a height of approximately 2 m. The instrument was deployed to monitor PM_{10} concentration with the PM_{10} specific cyclone installed. The pDR operates continuously while power is provided by the inbuilt battery. The monitoring record is therefore dis-continous with missing data in periods between battery failure and re-charging. A log of pDR operating times is shown in ***Table 11.***

Figure 16. A pDR monitor

Table 11. Log of pDR operating times

Number	Start Date	End Date Time	Duration
1	28 February	1 March	2 days
2	8 March	9 March	2 days
3	16 March	18 March	3 days
4	28 March	29 March	2 days
5	3 April	21 April	19 days

Diffusion tubes

Figure 17. A diffusion tube

A Diffusion tubes[141] are a simple and accessible tool to monitor inorganic compounds in the air - Nitrogen dioxide NO_2 and Sulphur dioxide SO_2 in the specific case. A tube has two caps, one of which contains a steel mesh disc covered with a chemical which absorbs the respective pollutant. The tube works by a process called molecular diffusion which means compounds will move from an area of high concentration to an area of low concentration.

The compounds in the air are at a higher concentration than those in the tube, so the compounds diffuse into the tube and collect on the absorbent at the end of the tube. As the compounds are absorbed, the low concentration in the tube is maintained, and therefore the process continues for the monitoring period.

Greenpeace - Bulgaria conducted a 3-month diffusion tube survey in Golemo Selo and Bobov Dol between December 2017 and March 2018.

Limit values for pollution

The emission of pollutants to air is regulated within the European Union. The pollutants monitored in this study are among those for which member states are required to maintain ambient air quality standards[142]. These standards are set out in the Air Quality Directive[143] (and four Daughter Directives) as summarised in ***Table 12***.

Table 12. European Ambient Air Quality Standards

Pollutant	Concentration ($\mu g/m^3$)	Averaging period	Permitted exceedances each year
SO_2	350	1 hour	24
	125	24 hours	3
PM_{10}	50	1 day	35
	40	Calendar Year	-
$PM_{2.5}$	25	Calendar Year	-
O_3	180	1 hour	-
	120	Maximum 8-hour running mean	25 days/year averaged over 3 years
NO_2	200	1 hour	18
	40	Calendar Year	-

Table 13 shows the World Health Organisation (WHO) Air Quality Guidelines. These are not legally binding through regulations in Bulgaria, but are a widely accepted benchmark for assessing air quality. The WHO guideline values are set for the protection of health, and are generally stricter than the comparable EU standards, which have been established through a political, rather than a scientific consensus.

Table 13. World Health Organisation Air Quality Guideline

Pollutant	Concentration ($\mu g/m^3$)	Averaging period	Permitted exceedances each year
SO_2	500	10 minutes	0
	20	24 hours	0
PM_{10}	50	24 hours	0
	20	Calendar Year	-
$PM_{2.5}$	25	24 hours	0
	10	Calendar Year	-
O_3	100	Maximum 8-hour running mean	0
NO_2	200	1 hour	0
	40	Calendar Year	-

In addition, Member States of the EU have committed to reducing their emissions of pollutants like sulphur dioxide (SO_2) and nitrogen oxides (NO_x) among others according to the National Emissions Ceiling Directive[144] which came into effect on 31st December 2016. Governments need to ensure both citizens and industries comply. Bulgaria's commitments under the Directive are shown in ***Table 14***.

Table 14. National Emissions Ceiling Directive Commitments for Bulgaria

	For any year from 2020 to 2029	For any year from 2030
SO_2 reduction compared with 2005	78%	88%
NO_x reduction compared with 2005	41%	58%
NMVOC reduction compared with 2005	21%	50%
NH_3 reduction compared with 2005	3%	12%
$PM_{2.5}$ reduction compared with 2005	20%	41%

Furthermore, emissions of certain pollutants into the air from combustion plants and industry are limited by the Industrial Emissions Directive (IED)[145]. The directive manages emissions of sulphur dioxide SO2, nitrogen dioxide NO2 and dust from combustion plants with a thermal input capacity equal to or greater than 50 MWth, and requires the use of Best Available Techniques (BAT) for managing environmental impact in industry.

Results

Particulate Matter of 10 micrometers or less in diameter PM_{10}

A total of five exceedances of the EU and WHO daily mean standard for PM10 of 50 µg/m³ were recorded during the different monitoring periods of the study. The EU legislation allows for 35 exceedances annually.

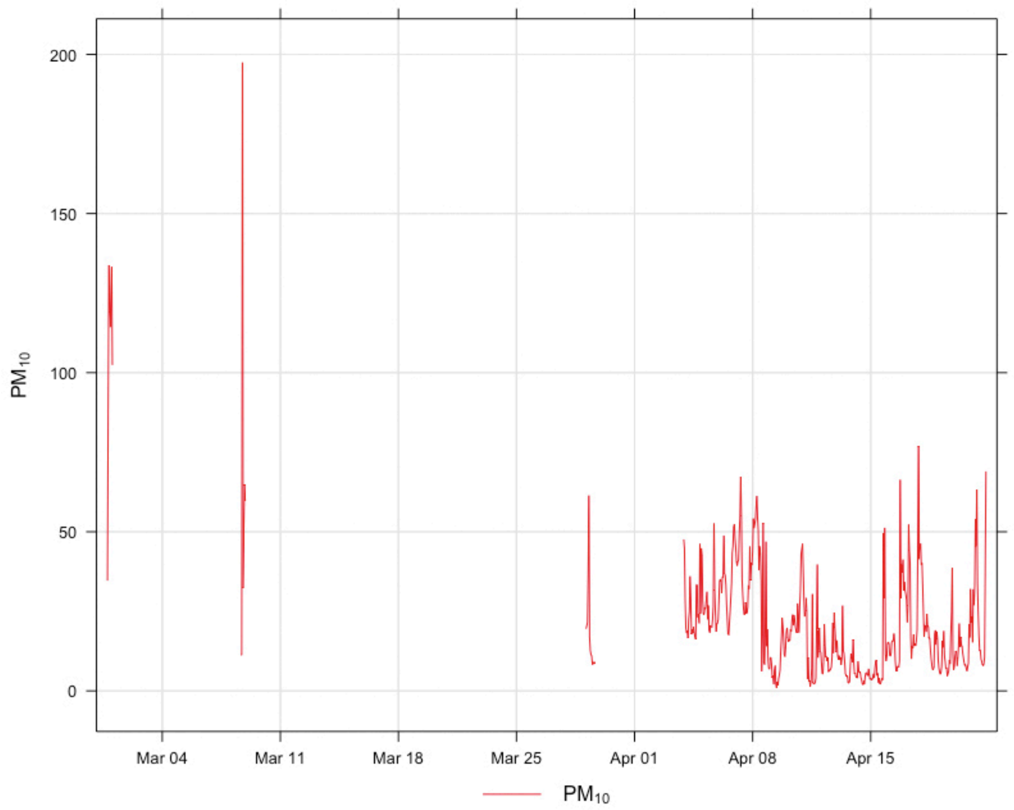
Table 15. Summary of measured daily mean PM_{10} standard exceedances (µg/m³)

Date	Daily Mean PM_{10}	Measuring device
28/02/19	102.4	pDR
01/03/19	54.5	pDR
08/03/19	57.3	pDR
17/03/19	54.6	pDR
09/05/19	120	EEA mobile monitoring station

Monitoring with the pDR was discontinuous with missing data in February and March being the result of power supply failures to the instrument. Near continuous monitoring was achieved between 3 April 2019 and 21st April 2019. During these periods four exceedances of the WHO and EU daily mean standard were measured.

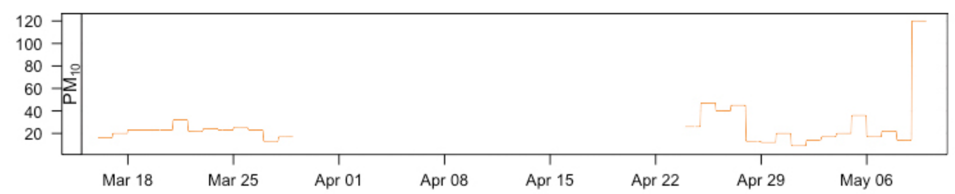
Hourly mean PM10 concentrations measured by the pDR monitor in Golemo Selo are presented in ***Figure 18***.

Figure 18. Concentration of PM_{10} (µg/m³) measured using the pDR instrument



According to the data of the EEA mobile station the EU daily mean standard and the WHO 24-hour mean guideline for PM_{10} of 50 µg/m3 was exceeded once (9 May 2019). 25 exceedances are permitted annually. Monitoring was only performed from 15 March 2019 - 29 March 2019, and 23 April 2019 - 11 May 2019. It is therefore likely that further exceedances of these standards would be recorded during the calendar year.

Figure 19. Monitored 24-hour mean PM_{10} concentrations (µg/m³) measured by the mobile monitoring station during two periods of monitoring in Golemo Selo in 2019



Particulate matter (PM)

Particulate matter (PM) consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. Burning solid fuels including coal for energy generation results in emissions of PM, among other pollutants. Some components of coal produce more particles when they are burned, meaning that the type of fuel used can affect the amount of PM that is produced. PM may be emitted directly (primary PM), or be formed in the atmosphere through chemical reactions (secondary PM). Particulate matter can be classified according to grain size. Particles with a diameter of 10 microns or less are known as PM_{10} and particles with a diameter of 2.5 microns or less are known as $PM_{2.5}$. PM_{10} can irritate a person's eyes, nose, and throat[146].

Even coarse PM_{10} particles can penetrate and lodge deep inside the lungs, while fine grained $PM_{2.5}$ can penetrate the lung barrier and enter the blood system, making them even more damaging[147]. Chronic exposure to particles contributes to various health impacts which may include cardiovascular effects such as cardiac arrhythmias and heart attacks, and respiratory effects such as asthma attacks and bronchitis[148]. The International Agency for Research on Cancer (IARC) has classified outdoor air pollution in general and in particular the PM in outdoor air pollution as carcinogenic to humans[149]. According to the WHO, PM affects more people than any other pollutant and has health impacts even at very low concentrations. There is no level of fine particle pollution that is known to be safe[150].

Sulphur Dioxide SO_2

The EU 1-hour mean standard for SO_2 of 350 µg/m³ was exceeded once (3 May 2019) during the monitoring of the mobile station. 24 exceedances are permitted annually. Monitoring was only performed from 15 March 2019 - 29 March 2019, and 23 April 2019 - 11 May 2019. It is therefore likely that further exceedances of these standards would be recorded during the calendar year.

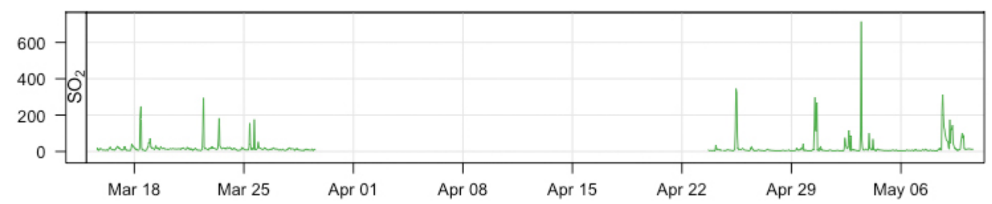
However, there were a further ***11 exceedances*** of the WHO 24 hour mean guideline for SO_2 of 20 µg/m³. ***(Table 16)***.

Date	Daily Mean SO_2
18/03/19	32.2
19/03/19	20.8
22/03/19	28.2
23/03/19	26.9
25/03/19	28.6
25/04/19	43.8
30/04/19	44.8
02/05/19	23.3
03/05/19	48.1
08/05/19	57.2
09/05/19	49.8

Table 16. Summary of measured WHO daily mean SO_2 guideline exceedances (µg/m³)

The diurnal cycle of SO_2 shows morning and evening peaks consistent with domestic solid fuel burning above the background concentration.

Figure 20: Monitored hourly mean SO_2 concentrations (µg/m³) measured by the mobile monitoring station during two periods of monitoring in Golemo Selo in 2019



Pairs of diffusion tubes were deployed in Bobov Dol and Golemo Selo in 2017 and 2018. The results from each pair for the SO_2 are in better agreement in Bobov Dol than Golemo Selo suggesting the results in Golemo Selo have a larger error.

Table 17. Summary of 2017-2018 Diffusion Tube Monitoring (µg/m³)

Location	Start Date	End Date	Concentration SO_2
Golemo Selo	16/12/2017	12/01/2018	187
			78
	12/01/2017	13/02/2017	36
			36
	13/02/2017	16/03/2017	37
			40
Bobov Dol	16/12/2017	12/01/2018	32
			36
	12/01/2017	13/02/2017	77
			73
	13/02/2017	16/03/2017	33
			31
Analysing Laboratory			Gradko

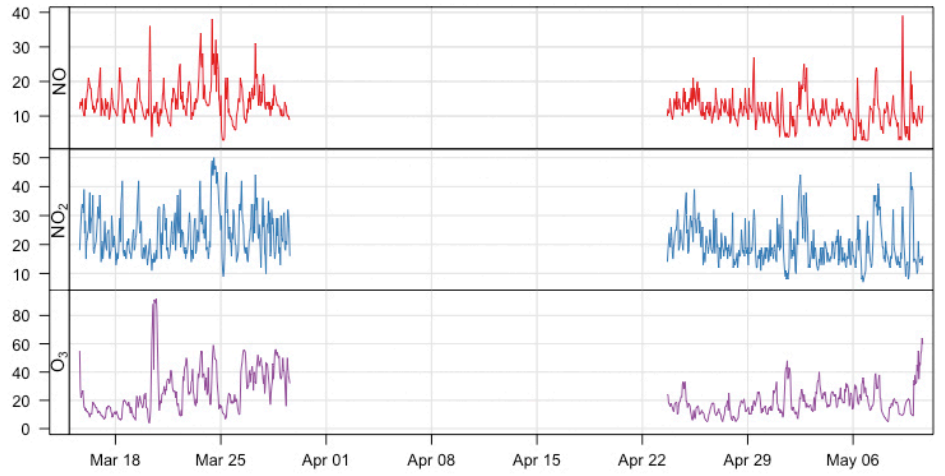
Sulphur Dioxide SO_2

SO_2 is a colourless gas with a sharp odour. It is produced from natural processes and anthropogenic activities like the burning of fossil fuels, especially coal. There is strong evidence of negative health impacts resulting from exposure to SO_2, including respiratory conditions such as chronic obstructive pulmonary disorder[151, 152], bronchitis[153] and non-communicable diseases such as stroke[154, 155], cardiovascular disease[156] and (via particulates) lung cancer[157]. When SO_2 combines with water, it forms sulfuric acid, the main component of acid rain which is detrimental for plants and animals.

Nitric oxides NO_x and Ozone O_3

The mobile monitoring station did not record exceedances of the EU air quality standards for NO_2 or O_3 during the periods of monitoring; however the short-term monitoring data do not allow an assessment for exceedances of the annual mean air quality standards.

Figure 21. Monitored hourly mean NO_x and O_3 concentrations (μg/m³) measured by the mobile monitoring station during two periods of monitoring in Golemo Selo in 2019



Analysis of the temporal variations in recorded NO, NO_2 and O_3 concentrations are presented in ***Figure 21***. There is a well pronounced diurnal cycle of NO_2 and O_3, where both species concentrations increase from overnight minima. The maximum O_3 concentration coincides with the hours of maximum insolation while NO_2 reaches two peaks each day. The midday NO_2 minima are likely the result of depletion caused by reactions in the presence of sunlight, which generate the O_3 and NO maximums at midday. Each NO_2 peak coincides with times associated with domestic fuel burning, traffic and other local combustion processes, before and after midday.

Nitrogen oxides NO_x

In the process of burning coal nitrogen contained in the fuel and molecular nitrogen from the atmosphere react to create nitrogen oxides (including nitrogen monoxide NO and nitrogen dioxide NO_2). These gases are referred to as NO_x. NO quickly oxidizes to form NO_2. NO_2 is a toxic gas which causes significant inflammation of the airways. The major sources of its anthropogenic emissions are combustion processes[158], primarily energy generation from fossil fuels like coal. As a pollutant it also plays an important role in the generation of $PM_{2.5}$. NO_x pollution is a major source of nitrate aerosols, an important fraction of PM, and also leads to the formation of ozone O_3, in the presence of ultravioletlight[159]. Nitrogen oxides have numerous impacts on human health, notably on the cardiovascular system and respiratory system, and they exacerbate symptoms of asthma, chronic obstructive pulmonary disorder, and other respiratory diseases[160, 161].

The NO_2 night-time minima do not fall below 15 μg/m³. In a rural area such as Golemo Selo, where there are limited sources of NO_2 at night, these elevated concentrations at night provide evidence to suggest that the regional background concentration is affected by emissions from the CFPP which operates on a near continuous basis.

Figure 22. Concentration of NO (Red), NO_2 (Green) and O_3 (Blue) measured by the Mobile Monitoring station (μg/m³). Plots show the mean and 95% confidence interval for each hour in the week

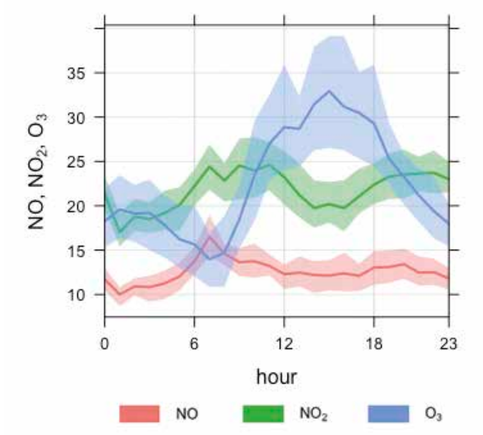


Figure 23. Diffusion tubes deployed in the area of Bobov dol

The results of the 3-month NO_2 and SO_2 diffusion tube survey deployed by Greenpeace - Bulgaria in Golemo Selo and Bobov Dol between December 2017 and March 2018 are presented in ***Table 18***. The duplicate NO_2 diffusion tubes deployed in each location show good agreement. The difference between duplicate samples is within 10% for both of the sites in the current study area. This provides good confidence in the measurement of average NO_2 concentrations during the monitoring period.

Table 18. Summary of 2017-2018 Diffusion Tube Monitoring (μg/m³)

Location	Start Date	End Date	Concentration NO_2
Golemo Selo	16/12/2017	12/01/2018	12
			12
	12/01/2017	13/02/2018	10
			11
	13/02/2018	16/03/2018	8
			8
Bobov Dol	16/12/2017	12/01/2018	19
			21
	12/01/2018	13/02/2018	19
			-
	13/02/2018	16/03/2018	15
			16
Analysing Laboratory			Buro Blauw

The recorded NO_2 concentrations are within the range expected for a semi-rural setting, with the highest monthly mean value recorded being 21 µg/m³ in Bobov Dol. Concentrations during each month of monitoring are significantly below 40 µg/m³, suggesting that exceedance of the EU annual average standard for NO_2 is not likely at the monitoring sites in Golemo Selo or Bobov Dol.

The mean NO_2 and O_3 concentrations measured by the AQMesh during the monitoring period are 41 and 40 µg/m³ respectively, significantly higher than the monitoring period means recorded by the 2018 diffusion tube survey for NO_2 or the results of the mobile monitoring station. The monitoring results are not directly comparable because the monitoring locations and monitoring periods differ.

Table 19. Summary of AQMesh Monitoring (µg/m³)

Pollutant	Mean	Maximum	Daily Maximum	Maximum 8-hour Running Mean	Maximum 24-hour Running Mean
NO_2	41	89.1	65.1	77.1	69
O_3	40.5	103	54.6	91.6	70

A direct comparison with the EU annual-average standard for NO_2 is not possible with short-term monitoring data. The monitoring NO_2 period mean (41 µg/m³) is higher than the annual-average standard (40 µg/m³). Therefore, if concentrations outside the monitoring period remain at similar levels the NO_2 standard will be exceeded. Neither the WHO guidelines, nor the EU standards for NO_2 (1-hour) or O_3 (8-hour running mean) were exceeded during the monitoring period at the AQMesh monitoring location.Analysis of the temporal variations in recorded NO, NO_2 and O_3 concentrations are presented in ***Figure 24*** and ***Figure 25***. The results of this analysis are in agreement with that undertaken using the mobile monitoring station data. There is a well pronounced diurnal cycle of NO_2 and O_3 and the interaction between NO_2, O_3 and NO results in O_3 depletion and a corresponding NO and O_3 peak in the middle of the day.

The NO_2 night-time minima do not fall below 20 µg/m3. This elevated night-time concentration provides evidence that emissions from the CFPP are affecting regional background concentrations of NO_2. By increasing background concentrations of NO_2, the 'head-room' to accommodate emissions from other sources before the standards are exceeded is reduced. The likelihood of an exceedance of the air quality standards for NO_2 is therefore increased as a consequence of the operation of the CFPP.

Figure 24. Concentration of NO (Red), NO_2 (Blue) and O_3 (Green) measured by the AQMesh (µg/m³). Plots show the mean and 95% confidence interval for each hour in the week

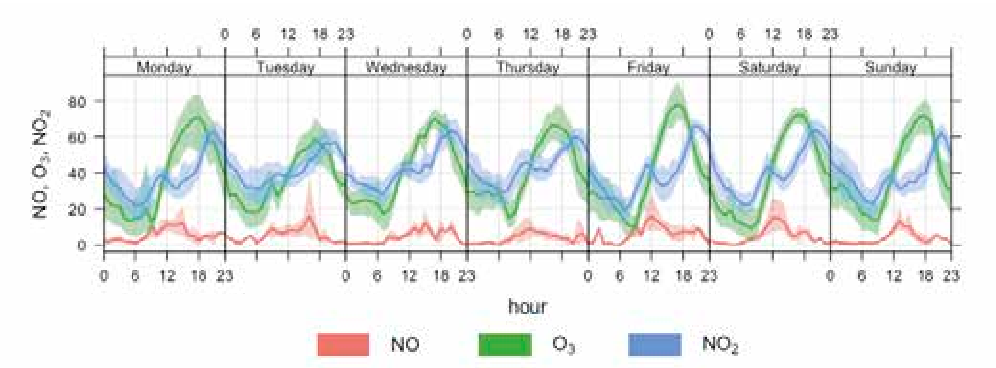
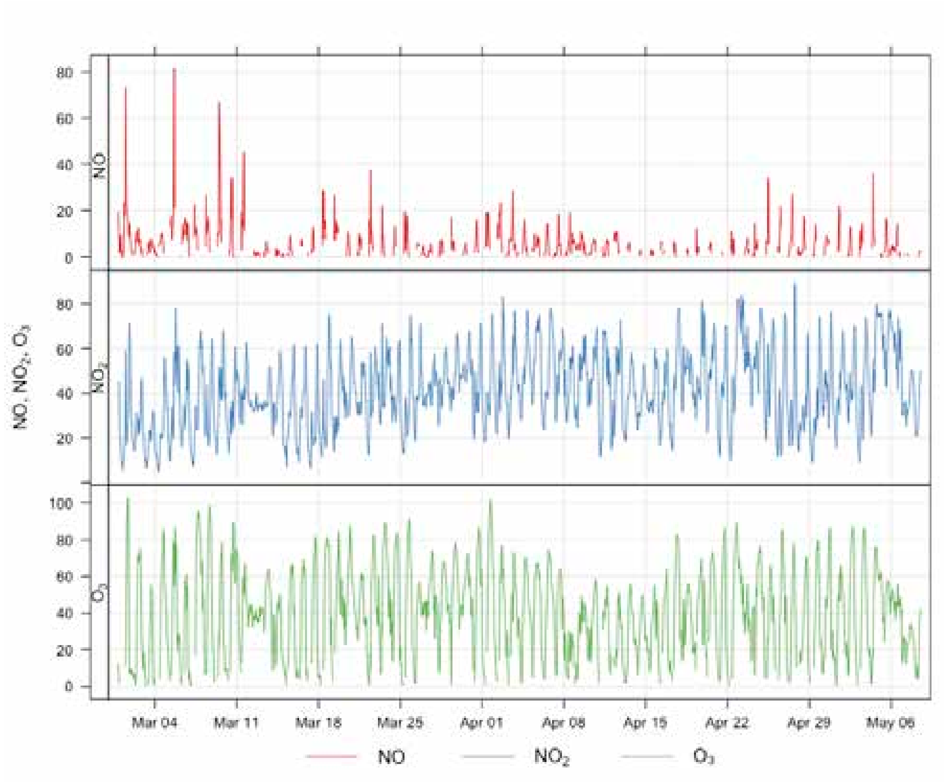


Figure 25. Concentration of NO (Red), NO_2 (Blue) and O_3 (Green) measured by the AQMesh (µg/m³)



Ozone O_3

While ozone in the stratosphere protects the Earth's surface from harmful ultraviolet radiation from the sun, at ground level ozone is an air pollutant and one of the major constituents of smog. It is not directly emitted by coal-fired power plants, but is formed as a secondary pollutant when other pollutants such as nitrogen oxides, including NO_2, and volatile organic compounds (VOCs) react with sunlight. That is why the highest levels of ozone pollution occur during periods of sunny weather. The health impacts of ozone pollution include chest pain, throat irritation and inflammation of the airways, impaired lung function and increased symptoms of bronchitis, emphysema and asthma. Ozone can increase susceptibility to infections[162]

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