Air pollution and associated health impacts in Novaci, North Macedonia

2021

CEE Bankwatch Network

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1. Executive summary

For the last forty years, the municipality of Novaci has been home to North Macedonia's REK Bitola complex, which consists of a 675 MW lignite power plant, open-cast mines and ash disposal sites. Its inhabitants have been breathing pollution emitted at the complex and its facilities in the form of dust, sulphur dioxide and nitrogen oxides. On nearly every side, the village is exposed to either coal extraction, burning or disposal activity: the power plant itself to the north-east, the main ash disposal and lignite mine site to the east, and lignite mining tailings to the south-east.

The main pollutants that affect the air quality in Novaci are dust particles (PM_{10} and $PM_{2.5}$) and sulphur dioxide (SO_2).

Between 1 January 2021 and 31 August 2021, the first ever long-term independent air pollution monitoring performed in the village of Novaci found that the legal daily limit value for PM_{10} of 50 micrograms per cubic metre (µg/m^3) was exceeded on 10 days, all of them in the months of January and February. The daily value recommended by the World Health Organization (WHO), 45 µg/m^3, was exceeded on 13 days. The highest value, of 111 µg/m^3, was recorded on 19 February, and was more than twice as high as the allowed limit.

For $PM_{2.5}$, the average concentration for the monitored period was 16.19 µg/m^3, which is more than three times higher than the WHO recommended for the entire year.

The recommended WHO limit value for SO_2 pollution was exceeded on 126 of the 243 days monitored, which means that on more than half of the days during the eight-month monitoring period, the air was more polluted than the health protective recommended limit. The legal hourly limit value was exceeded 41 times and the daily limit value 52 times.

According to the WHO, no level of air pollution can be considered 'safe', and the link between air pollution and respiratory and cardiovascular diseases is well established. Particulate matter with a size of 10 micrometres (PM_{10}) or 2.5 micrometres or less ($PM_{2.5}$) leads to the greatest health burden.

The $PM_{2.5}$ concentration alone is estimated to be responsible for a mortality rate of up to 8.43 per cent among adults in Novaci, which rivals some of the better-known pollution hotspots in the Western Balkan region, such as Tuzla in Bosnia and Herzegovina.

Although North Macedonia has pledged to phase out coal in the electricity sector by 2027, long-term exposure to coal pollution has already caused harm to local communities such as Novaci, and there is a risk that this harm will be prolonged unless remediation measures are implemented immediately and a redevelopment plan is agreed upon and rolled out.

North Macedonia's coal phase-out date is a double-edged sword: on the one hand it places the country at the top of the list of progressive, green countries in the region, but on the other, the Bitola power plant has been greenlighted by the North Macedonian environmental authorities to work without pollution control and continue polluting at similar levels for five more years. All strategic energy documents that were prepared or are in preparation point to the fact that the power plant, the main culprit of poor air quality in Novaci, will avoid compliance with pollution limits as long as its retirement is planned for the end of 2027.

As such, the affected local communities will experience no health benefits unless remediation actions are implemented immediately. Among the most urgent ones which would reduce local air pollution must be:

- An urgent issue of the plant's Integrated Pollution Prevention and Control (IPPC) permit.
- The closure and recultivation of depleted lignite mines and proper management of ash disposal sites to eliminate fugitive emissions.
- The expansion of the green belt around the entire complex, with vegetation that prevents pollutants from travelling longer distances.
- Keeping operating hours at REK Bitola as low as possible to comply with pollution limits from the national emissions reduction plan (NERP).
- Accelerating the work towards the energy transition and adhering to the coal phase-out date of 2027 set out in the Energy Strategy.
- Improving collaboration with local authorities on the implementation of air pollution reduction measures.

National and local decision makers are also urged to start the just transition planning process, in close cooperation with local decision makers in all municipalities affected by the coal phase-out. This should include ample public consultation as well as cooperation with the initiative for Coal Regions in Transition in the Western Balkans and Ukraine and the international donor community.

2. Introduction

Location and major sources of pollution

The municipality of Novaci is home to North Macedonia's REK Bitola complex, which consists of a 675 MW lignite power plant, open-cast mines and ash disposal sites. The village of Novaci is the administrative centre and the most populated settlement in the municipality. It is also the closest one to the complex.

The power plant is the biggest energy production facility in North Macedonia, on average producing between 45 and 50 per cent of the electricity in the country. It is also the biggest source of dust and sulphur dioxide emissions in the country.[1] Energy production in North Macedonia contributed 93 per cent of the SO_2 emissions in 2020,[2] and around 95 per cent of those are from the Bitola power plant. In 2020, the plant's stacks emitted 3,472 tonnes of dust particles and 84,513 tonnes of SO_2.[3]

As the closest settlement to these facilities, Novaci is significantly impacted by the pollution from REK Bitola. The stacks of the power plant are just 1.8 kilometres north-east of the village, the main ash disposal site is exactly two kilometres to the east and the open-cast lignite mine is four kilometres in the same direction. The tailings from the mine are dumped at a location 3.5 kilometres south-east of the village.

[1] *AD North Macedonian Power Plants, Annual Report on the Work of AD North Macedonian Power Plants for 2020, AD North Macedonian Power Plants, 2021.*

[2] *Macedonian Information Centre for Environment, Quality of the Environment in the Republic of North Macedonia – Annual Report 2020, Macedonian Information Centre for Environment, 2021.*

[3] *CEE Bankwatch Network, Centre for Research on Energy and Clean Air, Comply or Close - How Western Balkan coal plants breach air pollution laws and cause deaths and what governments must do about it, Comply or Close, 2021.*

Image 1: *Distribution of coal facilities (red areas) in relation to the monitoring location (green circle)* *Map source: Google Earth*

The positions of these facilities means that the village is significantly exposed to environmental pollution, either from continuous emissions from the power plant stacks, or from fugitive emissions from ash disposal, the mine and the tailings dump site.

The health impacts of air pollution

According to the WHO, no level of air pollution can be considered 'safe', and the link between air pollution and respiratory and cardiovascular diseases is well established. Particulate matter with a size of 10 micrometres (PM_{10}) or 2.5 micrometres or less ($PM_{2.5}$) leads to the greatest health burden.

The latest studies show that even the lowest levels of air pollution cause significant damage to health. Based on this new scientific knowledge, the WHO has very recently revised its air quality guidelines. The new Air Quality Guidelines recommend lower values for several pollutants, most notably for $PM_{2.5}$, which causes the greatest health burden, for which a new annual concentration of 5 µg/m^3 is now recommended. For nitrogen dioxide (NO_2), which has come under intense scrutiny in discussions on road transport and inner-city driving bans, a new annual concentration of 10 µg/m^3 is now recommended (down from the previous 40 µg/m^3).

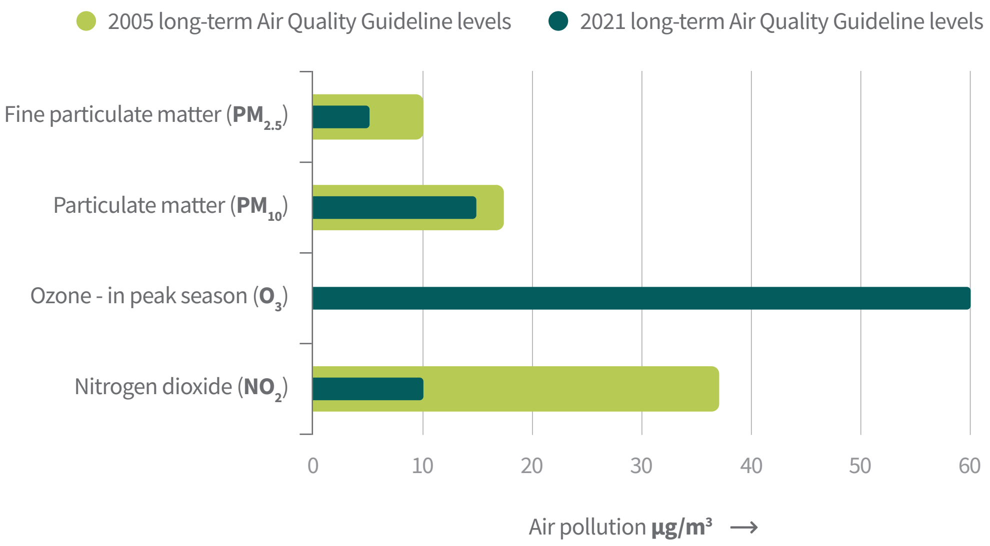

***Image 2:** Comparison of 2005 and 2021 WHO recommended limit values for certain pollutants in ambient air*

Annual mean PM concentrations in North Macedonia are significantly higher than what the WHO recommends.[4] In 2019, the annual mean for PM_{10} was five times higher compared to the new WHO guidelines (86 µg/m^3).[5]

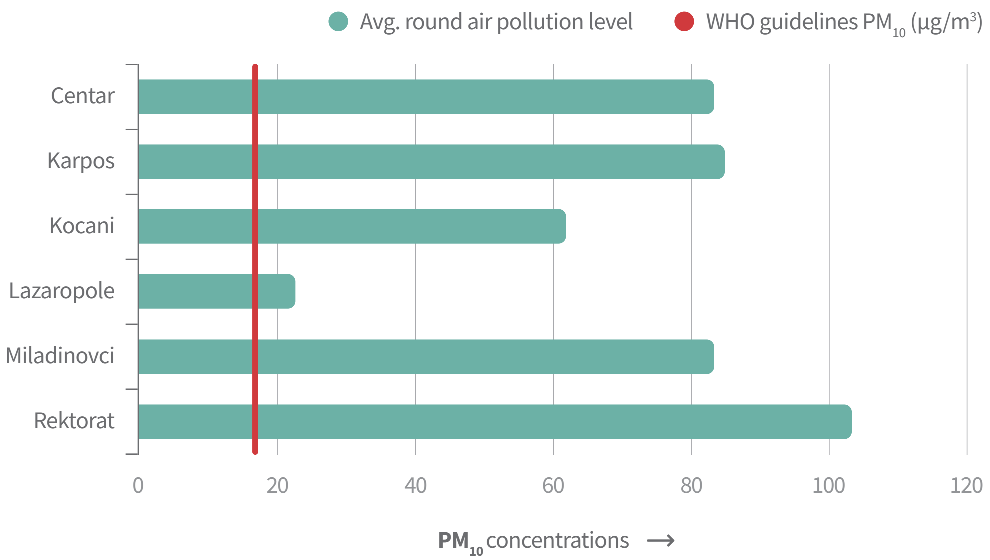

***Image 3:** PM_{10} concentrations in 2019 by station in North Macedonia in relation to WHO guidelines*[6]

[4] *World Health Organization, Air Quality Guidelines, World Health Organization, 21 September 2021.*

[5] *European Environment Agency, Europe's air quality status 2021- update, European Environment Agency, 2021.*

[6] *European Environment Agency, Europe's air quality status 2021- update, European Environment Agency, 2021.*

Breathing in particulate matter, even at low levels, can lead to physiological changes in the body that damage health. When inhaled, particles travel into the bloodstream and cause harm to our lungs and heart. They can cause strokes and lead to premature death. Studies also link particulate matter with harm to the healthy development of children, and diseases such as obesity and Alzheimer's. Poor air quality is also linked to chronic and acute respiratory diseases, which significantly degrade quality of life, such as bronchitis and the aggravation of asthma. Scientists continue to identify new ways that air pollution can harm our health; for example, there is increasing evidence linking air pollution to dementia and new evidence has shown that particles of air pollution travel through the lungs of pregnant women and lodge in their placentas, harming babies before they are born.

A recent report by the Health Effects Institute links fossil fuel combustion, a major source of air pollution, to more than one million deaths globally in 2017. This means that more than 27 per cent of all deaths can be attributed to outdoor fine particulate matter ($PM_{2.5}$) pollution.[7]

Key health facts[8]

- Air pollution is the sixth leading risk factor for premature death in North Macedonia. Leading causes of death in North Macedonia include ischemic heart disease, ischemic stroke, lung cancer, intracerebral haemorrhage and diabetes, while leading risk factors include high blood pressure, tobacco, high blood sugar, dietary risks and high body mass index.
- There are 118 deaths per 100,000 people attributable to air pollution in North Macedonia compared with 86 deaths per 100,000 people globally, adjusted for differences in age.
- Seven per cent of total air-pollution-attributable deaths in North Macedonia are in children under five, and 14 per cent are in people over 70.

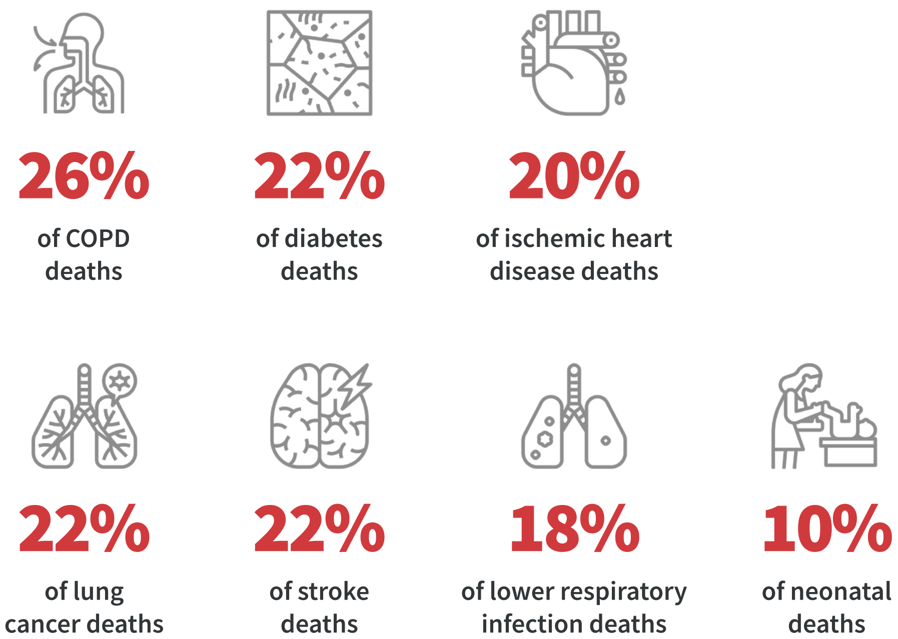

Image 4: *Percentage of deaths (by cause) attributed to air pollution in North Macedonia in 2019*[9]

Icon credits: Flaticon - Monkik

[7] *Health Effects Institute, A Global Assessment of Burden of Disease from Exposure to Major Air Pollution Sources, Health Effects Institute, 2021.*

[8] *Health Effects Institute, State of global air 2020 North Macedonia, Health Effects Institute, 2020.*

[9] *Health Effects Institute, State of global air 2020 North Macedonia.*

3. North Macedonia air quality legislative and strategic framework

National legislative framework

The North Macedonian ambient air quality legislation is closely aligned with that of the European Union. The European Commission has assessed that the legislative alignment on air quality is almost complete.

The umbrella legislation is the Law on Ambient Air Quality.[10] This Law includes the general provisions from the Ambient Air Quality Directive (AAQ Directive), the National Emission Ceilings Directive (NEC Directive) and the Large Combustion Plants Directive (LCP Directive).

Arising from the Law, sixteen pieces of implementing legislation have been adopted that are a direct transposition of the annexes of the above directives. The ones arising from the AAQ Directive are the:

- Decree on limit values for levels and types of pollutants in the ambient air and alert thresholds, deadlines for reaching the limit values, margins and tolerance for limit value, target values and long-term goals.[11] The decree and amendments define the standards for the following pollutants: sulphur dioxide, nitrogen dioxide, benzene, carbon monoxide, PM_{10}, $PM_{2.5}$, heavy metals (Pb, As, Cd, Ni), benzo (a) pyrene and ozone.
- Ordinance on the criteria, methodology and procedures for assessment of ambient air quality,[12] which defines the upper and lower thresholds for pollutants, methods for assessment of air quality, as well as the criteria for collection and calculation of statistical parameters.
- Ordinance on the content and the manner of relaying the data and information on the conditions in the ambient air quality management,[13] which defines how the public is to be informed and the types of reports in which the state of the air quality is presented.
- Ordinance on the methodology for monitoring ambient air quality,[14] which defines the reference methods for measuring the concentrations of pollutants, the criteria for determining the micro and macro locations of the measuring points, as well as the minimum number of measuring points in each zone/agglomeration.
- Ordinance on the detailed conditions for performing certain types of professional work, in terms of equipment, devices, instruments and appropriate business premises to be fulfilled by the entities that perform certain professional work for monitoring the ambient air quality.[15] This describes in detail the conditions that must be met by accredited laboratories for measuring ambient air quality.
- Ordinance on the detailed content and the manner of preparation of the national plan for protection of the ambient air.[16]
- Ordinance on the detailed content and the manner of preparation of the plan for improvement of the ambient air quality.[17]
- Ordinance on the detailed content and the manner of preparation of short-term action plans for ambient air protection.[18]

The limit values for pollutants relevant for this analysis are the same as those in the AAQ Directive.

[10] *Official Gazette of the Republic of North Macedonia no. 67/2004, 92/2007, 83/2009, 35/2010, 47/2011, 100/2012, 163/2013, 10/2015, 146/2015, 151/2021*

[11] *Official Gazette of the Republic of North Macedonia no. 50/2005, 4/2013, 183/2017*

[12] *Official Gazette of the Republic of North Macedonia no. 169/13*

[13] *Official Gazette of the Republic of North Macedonia no. 138/09*

[14] *Official Gazette of the Republic of North Macedonia no. 138/09*

[15] *Official Gazette of the Republic of North Macedonia no. 69/11*

[16] *Official Gazette of the Republic of North Macedonia no. 108/9*

[17] *Official Gazette of the Republic of North Macedonia no. 148/14*

[18] *Official Gazette of the Republic of North Macedonia no. 148/14*

Pollutant	Averaging period	Limit value
SO_2	1-hour 24-hour	350 µg/m^3, not to be exceeded more than 24 times a year 125 µg/m^3, not to be exceeded more than 3 times a year
NO_2	1-hour 1-year	200 µg/m^3, not to be exceeded more than 18 times a year 40 µg/m^3
PM_{10}	24-hour 1-year	50 µg/m^3, not to be exceeded more than 35 times a year 40 µg/m^3
$PM_{2.5}$	1-year	25 µg/m^3
CO	daily 8-hour mean	10 mg/m^3
O_3	daily 8-hour mean	120 µg/m^3, not to be exceeded on more than 25 days/year, averaged over 3 years

Table 1: *Limit values for pollutants in the ambient air, North Macedonian legislation*

In addition, the WHO recommends different, more stringent limit values[19] for the health protection of the population. These are the limit values used for the calculation of the health burden caused by air pollution.

Pollutant	Averaging period	Limit value
SO_2	24-hour	40 µg/m^3, 99th percentile (i.e. 3-4 exceedances per year)
NO_2	24-hour 1-year	25 µg/m^3, 99th percentile (i.e. 3-4 exceedances per year) 10 µg/m^3
PM_{10}	24-hour 1-year	45 µg/m^3, 99th percentile (i.e. 3-4 exceedances per year) 15 µg/m^3
$PM_{2.5}$	24-hour 1-year	15 µg/m^3, 99th percentile (i.e. 3-4 exceedances per year) 5 mg/m3
CO	24-hour	4 µg/m^3, 99th percentile (i.e. 3-4 exceedances per year)
O_3	daily 8-hour mean Peak season	100 µg/m^3, 99th percentile (i.e. 3-4 exceedances per year) 60 µg/m^3

Table 2: *Recommended limit values for pollutants in ambient air, WHO guidelines*

Other important provisions from the AAQ Directive are also properly transposed, such as the siting criteria for sampling points, assessment criteria, methodologies, preparation of air quality plans, etc. Based on the Law and the implementing legislation, a National Plan for Protection of Ambient Air and five air quality plans have been prepared for the Skopje agglomeration and the municipalities of Tetovo, Bitola, Veles and Strumica.

[19] *World Health Organization, WHO Global air quality guidelines, World Health Organization, 2021.*

Local air quality plans

The municipality of Bitola neighbours Novaci, the subject of this analysis. The air quality plan for Bitola, among other things, emphasises the importance of the power plant in Novaci as a significant source of air pollution.

The plan also offers dispersion models for SO_2 and NO_2 emissions from the power plant and from them it is obvious that the plant has an impact on the entire area, but the main blow is taken by the villages in the Novaci municipality.

The main shortcoming of the plan is that it includes measures just for the municipality of Bitola. The AAQ Directive and the national legislation require that the plan is prepared for a zone or agglomeration where there are exceedances of the limit values, not just one municipality.

The initial zoning of the country makes the implementation of this requirement complicated since the Western Zone where Bitola and Novaci are located has many different regions with different sources of pollution. In this case, the plan should have at least included the neighbouring municipalities, since they are facing similar issues and are mostly impacted by the single biggest source of air pollution in the country. That way the air quality plan would have had measures targeted at the operation of the plant, which is now not the case.

Contrary to this local plan, the national plan mentions the need for modernisation of the power plant to meet emissions standards. This measure, like many others, has not been implemented. But this plan, which was for the period from 2013 to 2018, is already outdated, and there have been many new developments – such as the plans to phase out coal in the country by 2027 – that make it completely inadequate now.

This weak implementation of the AAQ Directive (but also other air quality legislation) is highlighted in every country progress report[20] by the European Commission, with insufficient allocation of financial resources, weak inter-sectoral cooperation and limited coordination between central and local authorities as the main issues identified.

Recognising the pressing need to tackle air pollution, in 2021, several mayors of the most polluted municipalities in the Western Balkans signed the Declaration of the Clean Air Regions Initiative.[21]

Bitola is among the cities included in this initiative, which aims to develop, adopt and maintain Local Air Quality Action Plans with ambitious local air quality targets, policies and measures.

[20] *European Commission, North Macedonia Report 2021, European Commission, 19 October 2020.*

[21] *Energy Community, Clean Air Regions Initiative, Energy Community, accessed 31 January 2022.*

4. Air pollution in Novaci and the wider Bitola region (official situation, local protests, independent monitoring)

The authors of this paper are convinced that the proximity of the thermal power plant and ash deposit play a significant role in the PM_{10} and $PM_{2.5}$ pollution in Bitola, yet the source of pollution has not been officially stated. For three successive years prior to our analysis, the Ministry for Environment in North Macedonia claimed that a chemical analysis as well as a study about the sources of pollution was underway, but still no results have been published.

After massive protests[22] attended by thousands of Bitola's residents in 2014 and 2015, the Ministry drew up several urgent measures to decrease pollution levels, but the government refused to undertake any of them. Protests were organised again in 2016, but much remained unchanged.

Official air quality monitoring

According to the 2021 air quality report by the European Environmental Agency, North Macedonia's annual mean value of $PM_{2.5}$ over 30 µg/m³ is double the EU-28 average,[23] and six times above the 2021 guidelines[24] issued by the WHO, which recommends a $PM_{2.5}$ annual average of only 5 µg/m³.

Although there is no official air quality monitoring station in the municipality of Novaci, an overview of the air quality can be extrapolated from the data from the two monitoring stations in nearby Bitola. There are also three monitoring stations owned by REK Bitola, but they are not regulated and their data are not published.

Official data from the national annual report on the Quality of the Environment in the Republic of North Macedonia for 2020 show that the instruments for monitoring PM_{10} and $PM_{2.5}$ at the Bitola 1 station were not operational for more than a quarter of the year, which makes the data unverifiable.[25]

The Bitola 2 station recorded 79 exceedances of the daily limit value for PM_{10}. The average annual concentration was lower than the limit value. For $PM_{2.5}$, the annual average was 26 µg/m³, just about the limit value of 25 µg/m³.

Regarding SO_2 pollution, the hourly and daily limit values were not exceeded at either the Bitola 1 or Bitola 2 stations. However, they had the highest annual average value, more than twice the other stations in the country, which is not surprising considering the relative proximity of the coal power plant in Novaci.

From the unofficial information available for 2021, the number of exceedances of the daily limit value for PM_{10} on the Bitola monitoring stations seems to have been somewhat lower than in 2020. There are 48 recorded exceedances at the Bitola 1 station and 47 at the Bitola 2 station. The annual average at Bitola 1 is 30 µg/m³ and at Bitola 2 34.4 µg/m³.

22 24Vesti Televizija, Protest for clean air in Bitola, N. Macedonia, Dailymotion, September 2012.

23 European Environment Agency, North Macedonia – air pollution country fact sheet, European Environment Agency, 7 December 2021.

24 World Health Organization, WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, World Health Organization, 22 September 2021.

25 According to the Air Quality Directive and the national legislation, a minimum required proportion of valid data needs to be collected for checking validity when aggregating data and calculating statistical parameters. The requirements are: 75 per cent (i.e. 45 minutes) for assessment of one-hour values; 75 per cent (i.e. 6 hours) for eight-hour values; 75 per cent of the hourly averages (i.e. at least 18-hour values) for 24-hour values; and 90 per cent of the one-hour values or (if not available) 24-hour values over the year for annual mean. If less than the required data is available during the analysed period, the average value for that period is not considered valid.

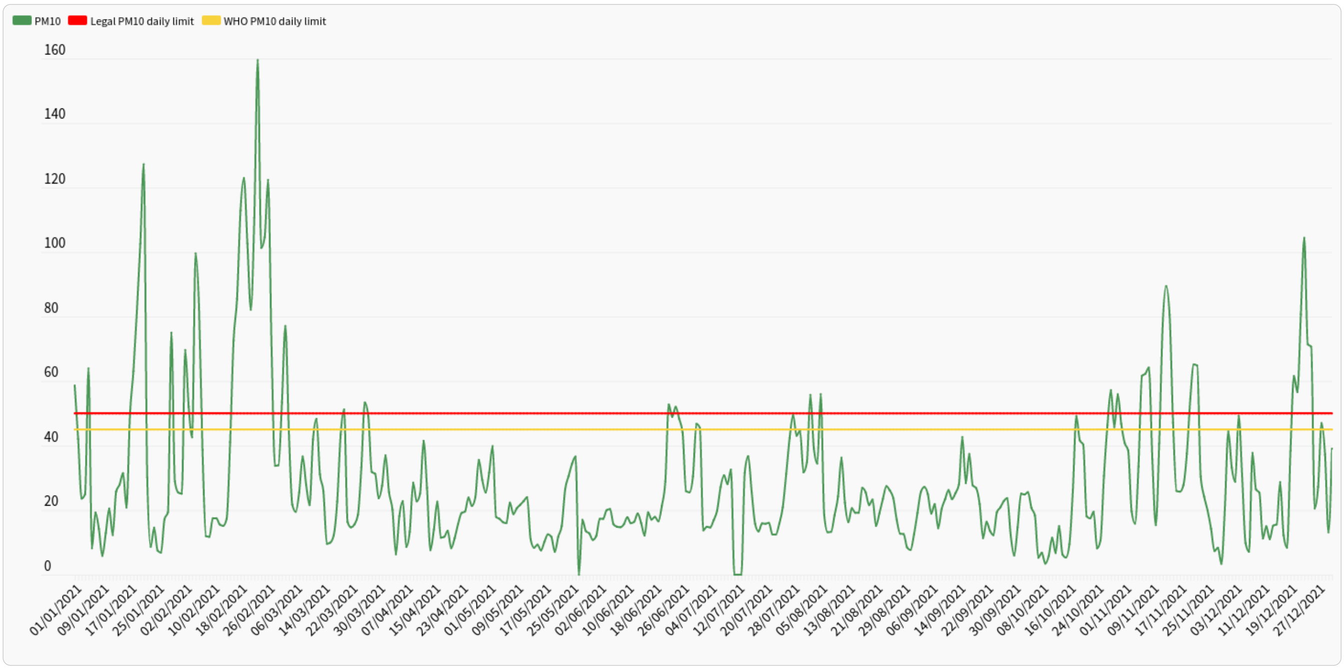

Image 5: *Daily PM_{10} values from the Bitola 1 monitoring station in 2021 compared to the legal and WHO limit values*

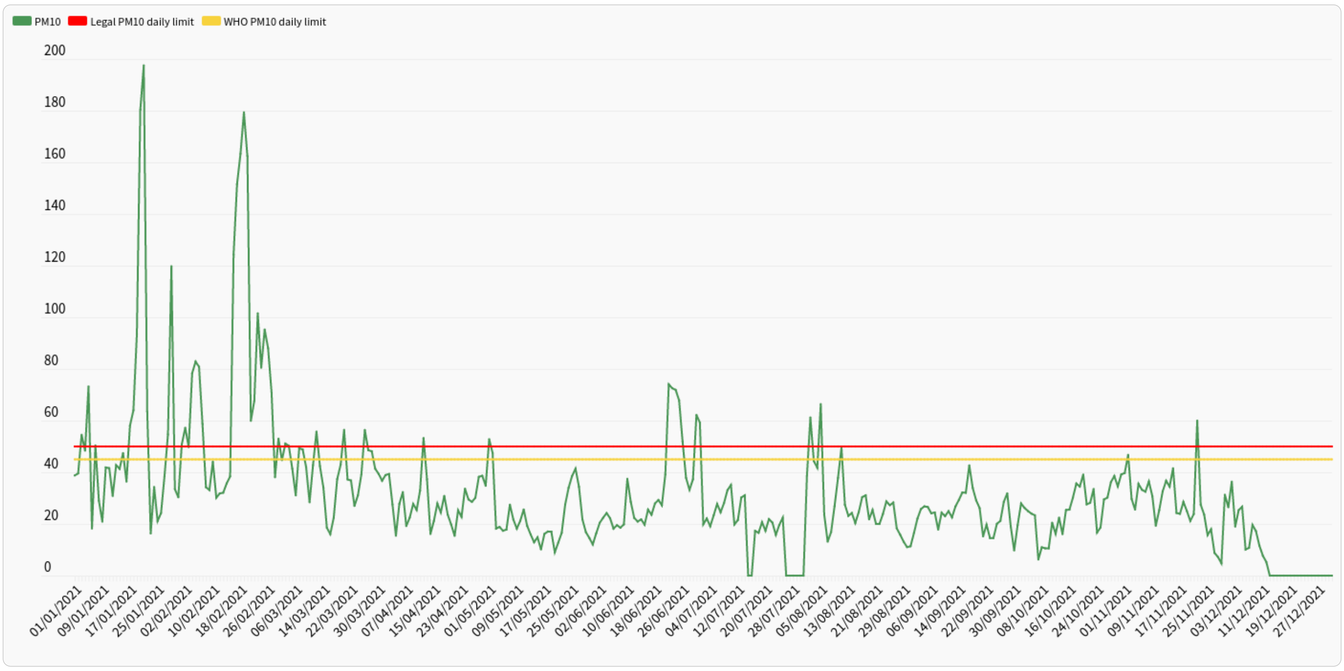

Image 6: *Daily PM_{10} values from the Bitola 2 monitoring station in 2021 compared to the legal and WHO limit values*

Independent monitoring of dust pollution in Bitola and Novaci

Independent dust pollution monitoring has been performed twice in the city of Bitola and once in Novaci. During the first attempt, in January 2017, the pollution levels were so high that after only a few days, the machine's filters and measurement chamber were contaminated and it had to be sent for clean-up and re-calibration. The monitoring was resumed for 30 days, between 5 June 2017 and 4 July 2017.

In Bankwatch's independent monitoring of dust particles during the summer of 2017, the measured $PM_{2.5}$ was above the EU's limit value for the annual average on seven out of 29 days observed, i.e. for 25 per cent of the time.

The EU PM_{10} limit for the daily average was breached on 5 days out of 29 observed. Over the course of one year, the PM_{10} limit may be exceeded no more than 35 times. If in June – a month when individual wood stoves were not contributing to this pollution – Bitola recorded five exceedances, limiting them to 35 for the whole year seems like a distant wish. The observation period was also one when schools are on holiday and people are already leaving town for their summer holidays, so traffic numbers were lower than usual.

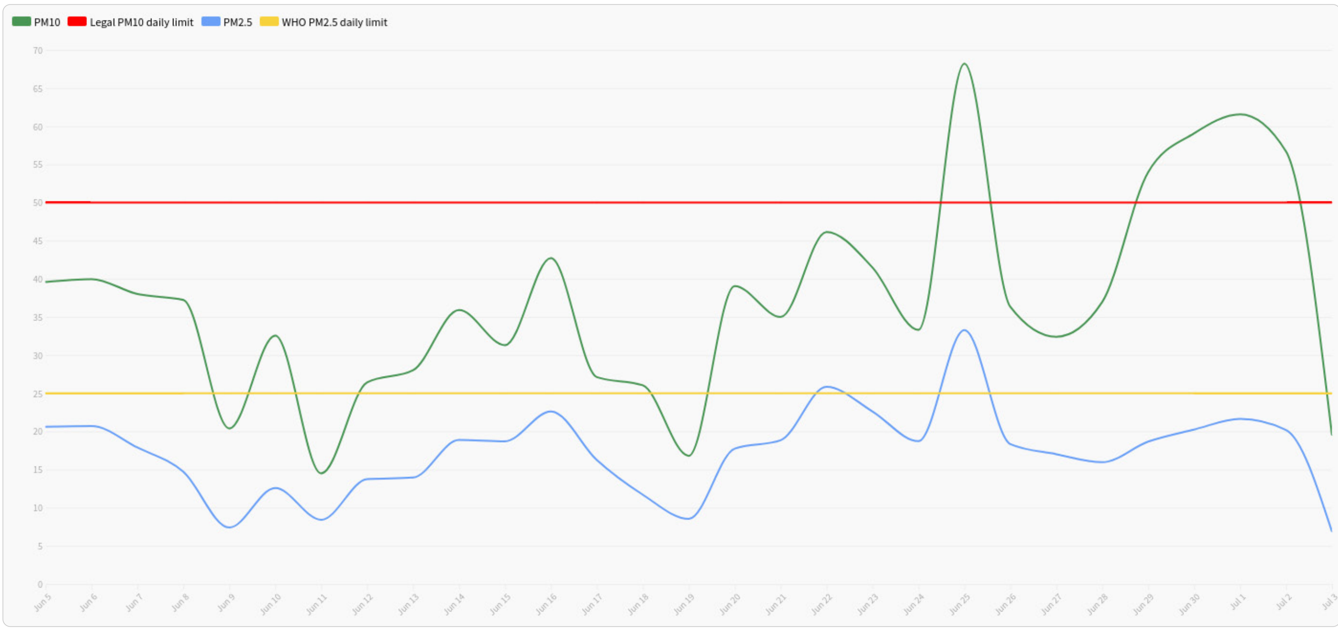

Image 7: *Measured PM_{10} and $PM_{2.5}$ concentrations during Bitola independent monitoring in 2017*

The dust collected in the filters of the environmental monitor used for independent monitoring was sent for analysis at a certified laboratory in Romania.

Out of the nine chemical elements that were tested for,[26] the dust collected by the filter in Bitola's air showed relatively high concentrations of selenium and chromium (1.5 micrograms/filter, and 0.5 micrograms/filter, respectively).

Selenium (Se) is released into the air through coal and oil combustion:

> People that eat a lot of grains that grow near industrial sites may experience a higher exposure to selenium through food. Exposure to selenium through drinking water may be increased when selenium from hazardous waste disposals ends up in water wells. Exposure to selenium through air only comes about in the workplace usually. It can cause dizziness, fatigue and irritations of the mucous membranes. When the exposure is extremely high, collection of fluid in the lungs and bronchitis may occur.[27]

Coal burning is also responsible for releasing the environmentally sensitive element chromium (Cr) into the atmosphere. Chromium migrates to the environment through stack emissions and can leach out from solid coal-burning byproducts, thereby causing adverse effects on the ecosystem:

> Chromium can migrate via and enrich coal combustion products during the coal combustion process, causing adverse effects on human health and the environment when released. Inhalation cancer and non-cancer risks associated with chromium emissions from coal-burning are large compared with other elements, with it being identified as a hazardous pollutant in the USA 1990 Clean Air Act Amendments and in the Canadian Environmental Protection Act of 1995.[28]

[26] *Aluminium, arsenic, beryllium, cadmium, chromium, mercury, nickel, lead and selenium*

[27] *Lenntech, Chemical properties of selenium - Health effects of selenium - Environmental effects of selenium, Lenntech, accessed 31 January 2022.*

[28] *Zhonggen Li et al., Behaviors of Chromium in Coal-Fired Power Plants and Associated Atmospheric Emissions in Guizhou, Southwest China, Atmosphere 11, no. 951 (6 September 2020).*

The independent monitoring in Novaci was conducted during a 30-day period in November and December 2018. The results of that monitoring showed that the air quality in the small village is much worse than it is in the city of Bitola. During the monitored period, the 50 μg/m^3 daily average limit for PM_{10} was exceeded on 22 days in one month. This makes up nearly two-thirds of what is allowed for the whole year – 35 exceedances. Half of those exceedances were two or more times over the limit. A deeper analysis of the results shows hourly mean values up to 400 μg/m^3, with short-time values regularly going up to 800 μg/m^3.

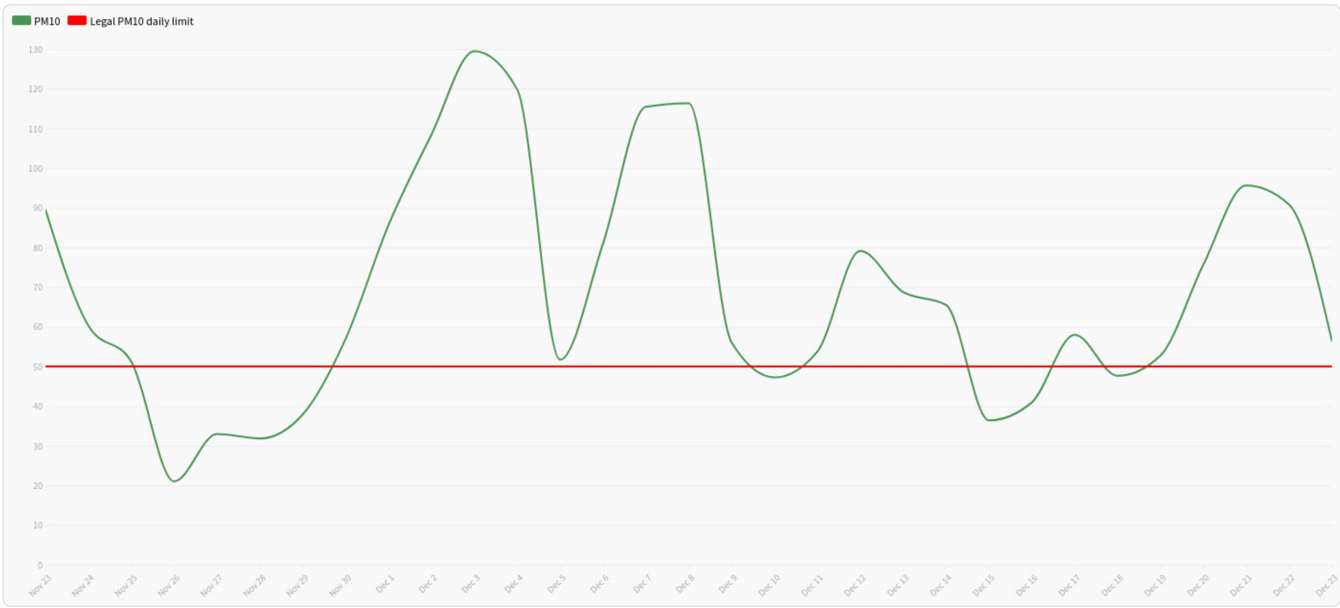

Image 8: *Measured PM_{10} concentrations during Novaci independent monitoring in 2018*

The situation with fine particles ($PM_{2.5}$) is even worse. The daily average limit recommended by the WHO is 25 μg/m^3, and only three exceedances per calendar year are allowed. During the observed period, we registered 27 exceedances, with values going up to three times above this limit and pushing the monthly average up to 47 μg/m^3 during the observation period.

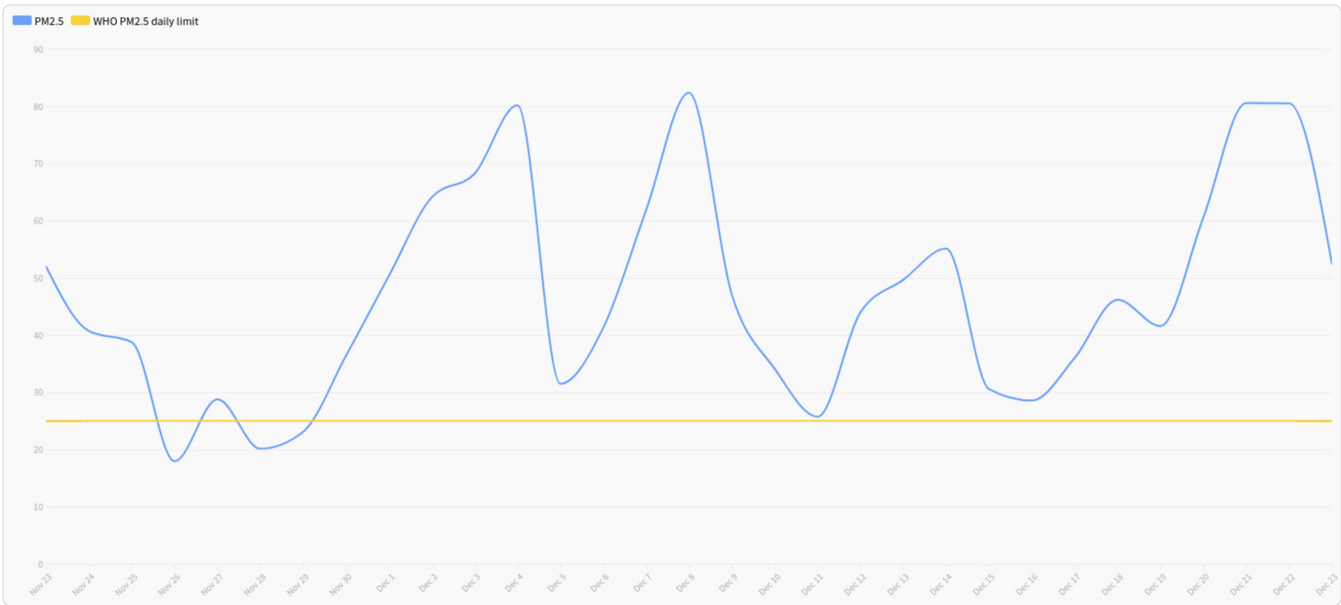

Image 9: *Measured $PM_{2.5}$ concentrations during Novaci independent monitoring in 2018*

Considering that the village is less than two kilometres from the power plant, these results are not surprising. The situation called for a longer monitoring period, with a more in-depth analysis.

5. Results of long-term independent air quality monitoring

For the purposes of this analysis, the air quality in the village of Novaci was monitored for eight months in one calendar year, from 1 January 2021 until 31 August 2021. Six different pollutants were measured – PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and O_3, as well as basic meteorological data like temperature, humidity, pressure, wind speed and wind direction.

The monitoring site was chosen to provide the best quality data on how the surroundings impact the air quality in the village. It was set up near the eastern edge, in a space that is open towards the power plant on one side and the village on the other side. The number of nearby sources that might significantly interfere with the results of the analysis was limited, including the main road which was almost 100 metres away.

The comprehensive data that were collected during the monitoring period allows for an extensive analysis[29] of the air quality in the village of Novaci and how much it is impacted by the nearby coal-fired power plant and its accompanying facilities.

During the monitored period, the concentrations of NO_2, CO and O_3 were well within the legal limit values, which is why they are not analysed in more detail here.

The main pollutants that worsen the air quality in Novaci are dust particles (PM_{10} and $PM_{2.5}$) and sulphur dioxide (SO_2).

Pollution with particulate matter (PM_{10} and $PM_{2.5}$) in Novaci

The PM_{10} concentration is regulated in the AAQ Directive and North Macedonian legislation with a daily limit value of 50 µg/m^3, which must not be exceeded more than 35 times in one calendar year, and an annual limit value of 40 µg/m^3. The WHO has stricter recommended limit values that provide better health protection – a daily limit value of 45 µg/m^3, which must not be exceeded more than three times in one calendar year, and an annual limit value of 15 µg/m^3.

Between 1 January 2021 and 31 August 2021 the legal daily limit value was exceeded on 10 days, all of them in January and February. The WHO recommended daily value was exceeded on 13 days. The highest value of 111 µg/m^3 was recorded on 19 February, and was more than twice as high as the allowed limit.

The average concentration for the whole monitored period was 16.64 µg/m^3. This means that for the whole year, if similar conditions remained, it would probably exceed the WHO health protective limit. $PM_{2.5}$ has an annual limit value of 25 µg/m^3 in the legislation. The WHO, however, recommends a daily limit of 15 µg/m^3 that must not be exceeded more than three times in one calendar year and an annual limit of 5 µg/m^3.

The average for the monitored period was 16.19 µg/m^3, which is more than three times as high as the WHO recommended level for the entire year.

[29] *A detailed explanation of the monitoring device, the site selection and the methodology used for the following analysis are given in Annex II.*

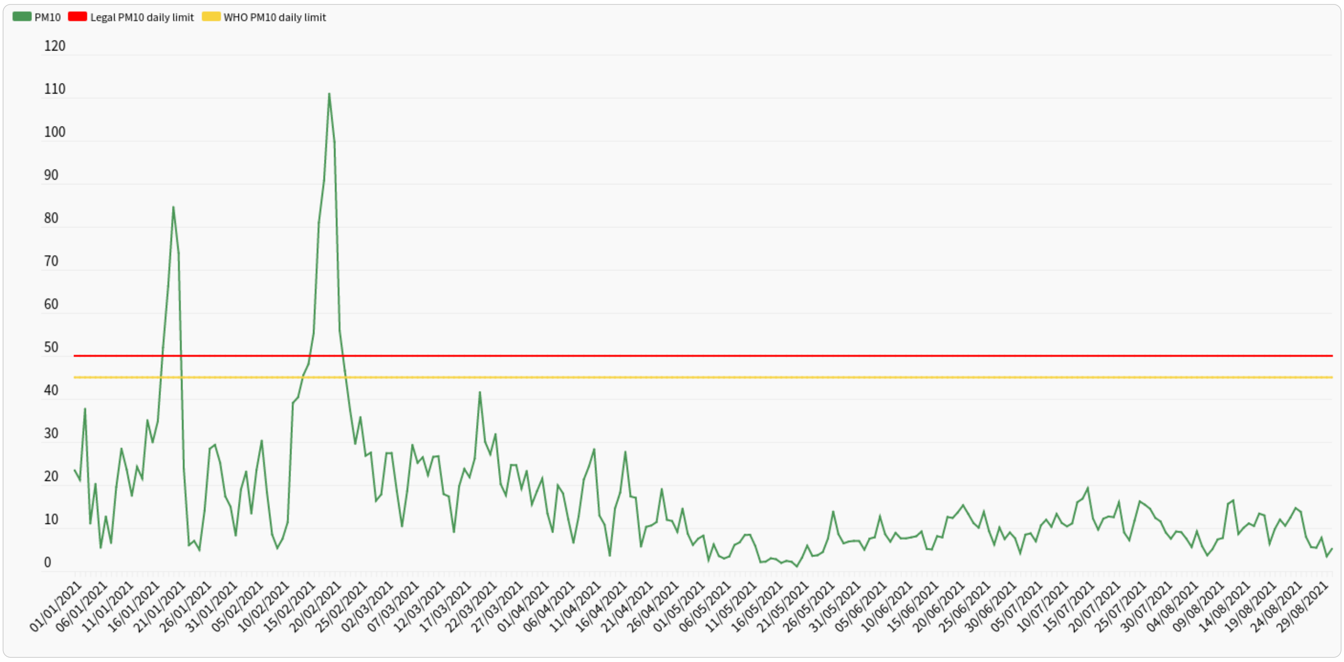

__Image 10:__ Average daily PM_{10} concentrations (green line) during Novaci independent monitoring in 2021, compared to legal PM_{10} daily limit value (red line) and WHO recommended PM_{10} daily limit (yellow line)

The recorded daily values compared to the WHO recommended value show that $PM_{2.5}$ concentrations were higher than what is considered healthy on 91 of the monitored days.

The highest concentration was on 19 February, 107 µg/m^3 – more than seven times as high as is recommended.

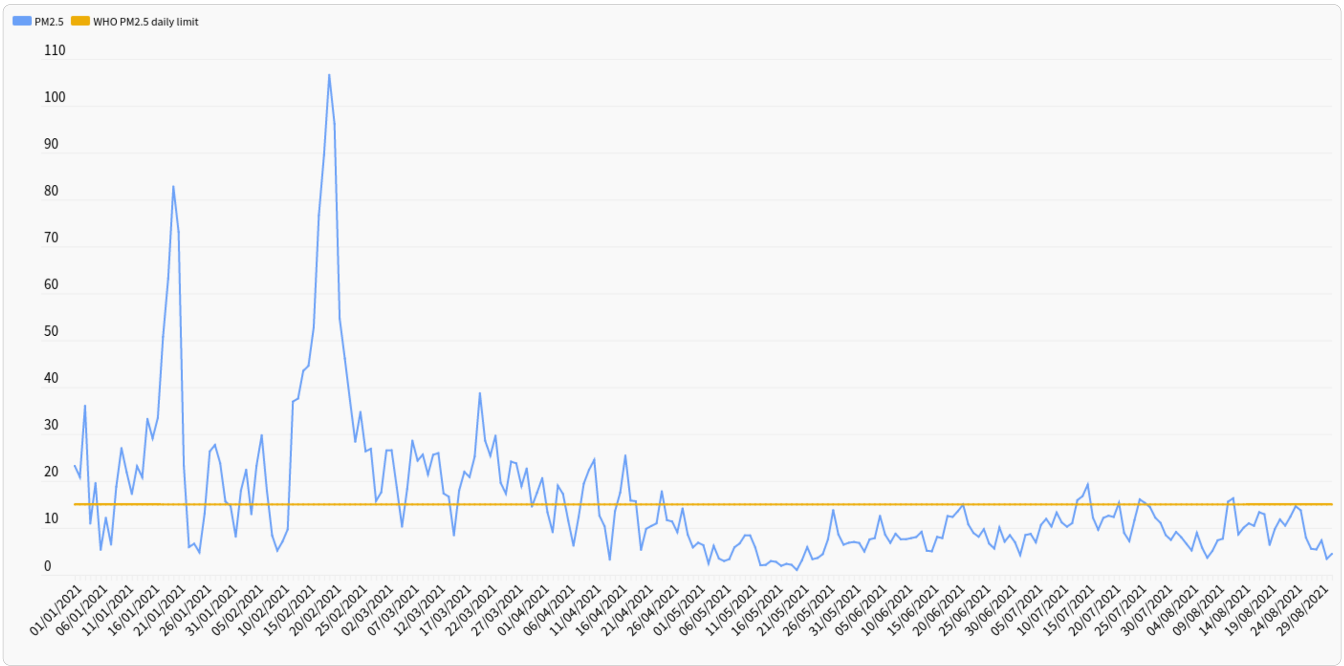

__Image 11:__ Average daily $PM_{2.5}$ concentrations (blue line) during Novaci independent monitoring in 2021, compared to WHO recommended $PM_{2.5}$ daily limit (yellow line)

Pollution with sulphur dioxide (SO_2) in Novaci

The concentration of sulphur dioxide (SO_2) is regulated as an hourly limit value of 350 µg/m³ that must not be exceeded more than 24 times a year, and a daily limit value of 125 µg/m³ that must not be exceeded on more than three days in one calendar year. The daily limit value recommended by the WHO is a lot stricter – 40 µg/m³.

In the monitored period, the hourly limit value was exceeded 41 times, which means that the legal standard was breached. The highest hourly value that was recorded was 370 µg/m³ on 31 July.

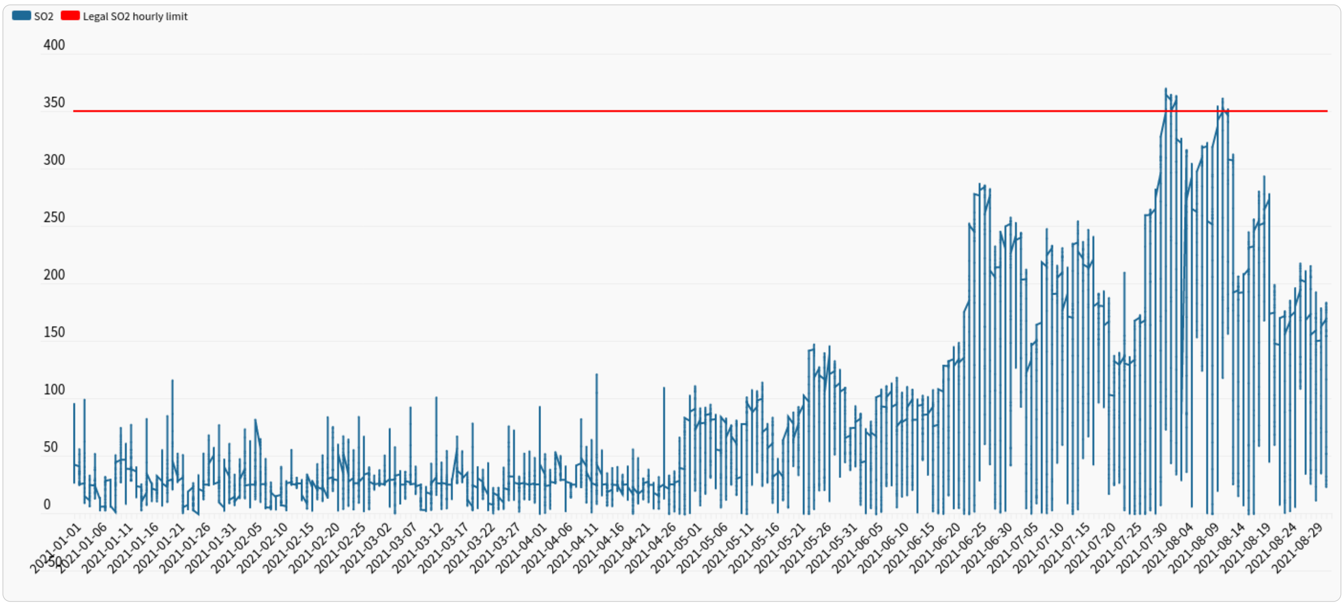

Image 12: *Average hourly SO_2 concentrations (blue line) during Novaci independent monitoring in 2021, compared to legal SO_2 hourly limit (red line)*

The SO_2 legal daily limit value was exceeded 52 times. The highest concentration was 278 µg/m³ on 11 August, more than double what is legally allowed. The recommended WHO limit value was exceeded on 126 of the 243 total days monitored, which means that on half of the days, the air was more polluted than the health protective recommended limit.

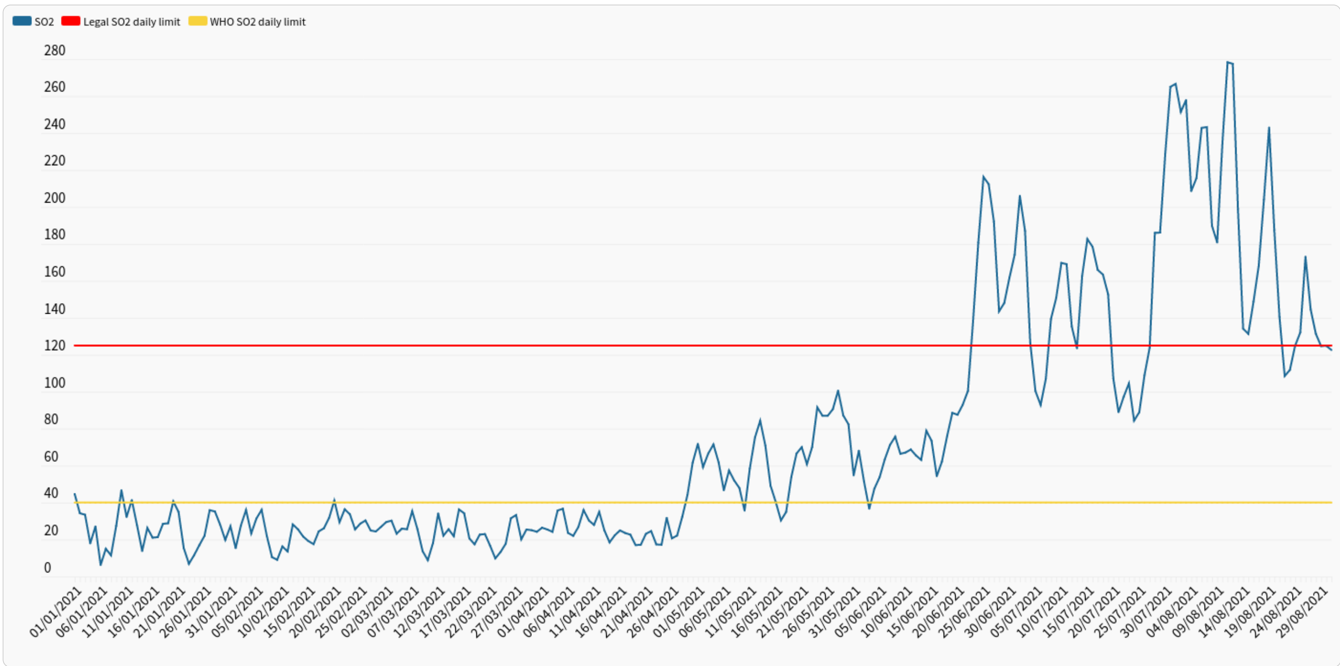

Image 13: *Average daily SO_2 concentrations during Novaci independent monitoring in 2021, compared to legal SO_2 daily limit (red line) and WHO recommended SO_2 daily limit (yellow line)*

Main sources of air pollution in Novaci

In order to determine possible sources of these pollutants, the data from the shortest available time interval is analysed, in this case 30-minute mean values. From those values the peaks in pollution are determined.

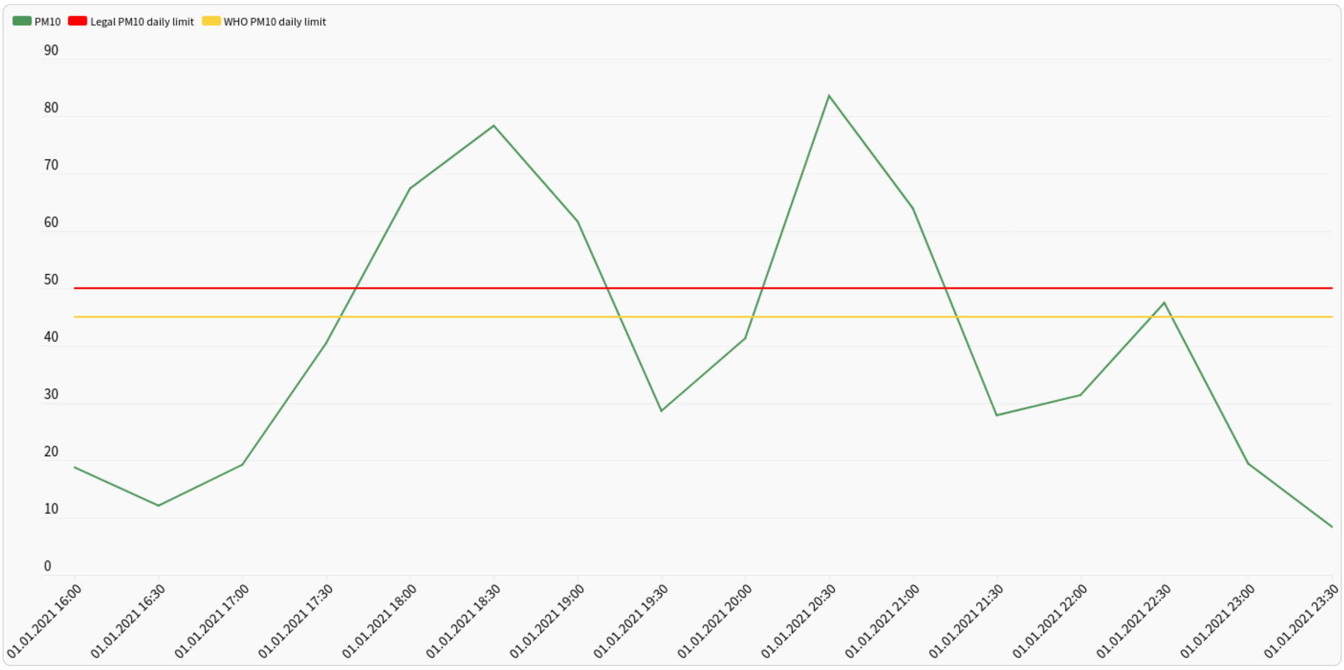

Image 14: *30-minute PM_{10} concentrations (green line) in Novaci between 16:00-23:30 on 1 January 2021. The legal PM_{10} daily limit value (red line) and WHO recommended PM_{10} daily limit (yellow line) do not apply for short-term measurements and are for reference only.*

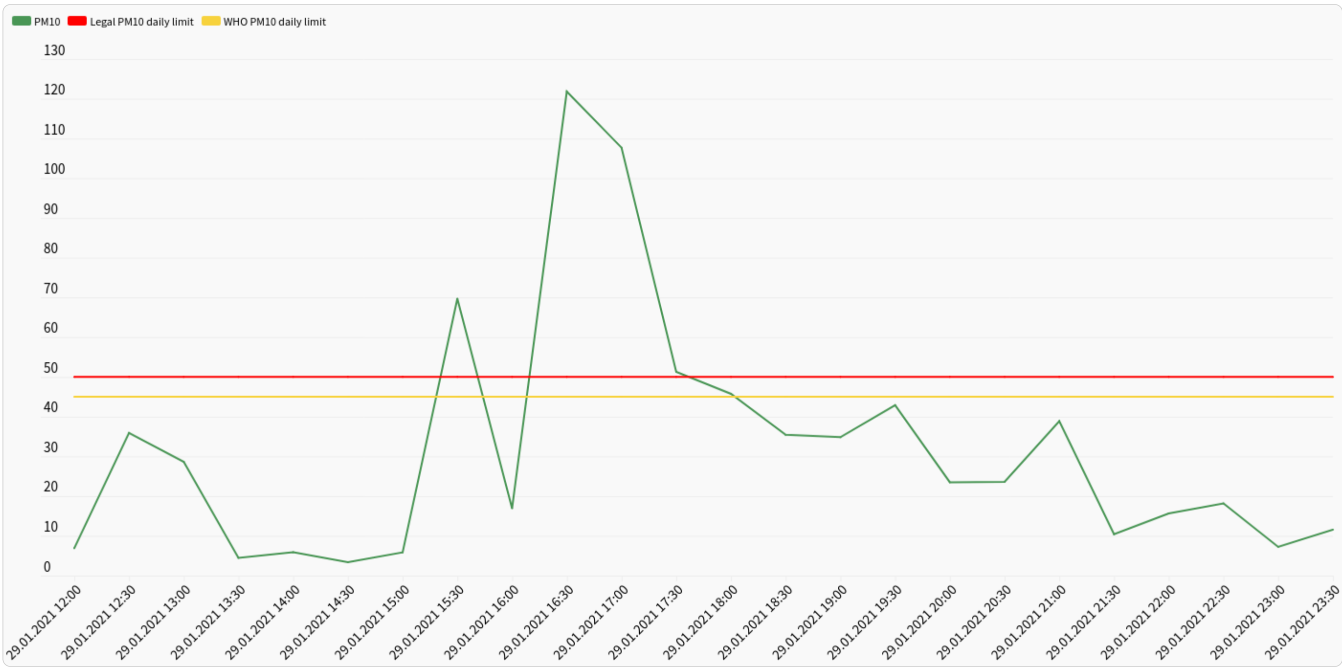

Image 15: *30-minute PM_{10} concentrations (green line) in Novaci between 12:00-23:30 on 29 January 2021. The legal PM_{10} daily limit value (red line) and WHO recommended PM_{10} daily limit (yellow line) do not apply for short-term measurements and are for reference only.*

By using the wind direction data, the general direction where the main pollution is coming from can be determined and displayed as a pollution rose. From these roses, it is obvious that on most occasions the majority of the PM_{10} is sourced east of the monitoring station. When these pollution roses are compared to the layout of the area around the monitoring station, the conclusion is that the power plant and its accompanying facilities are an important contributor to the air pollution in Novaci because east of the station there are no other possible sources.

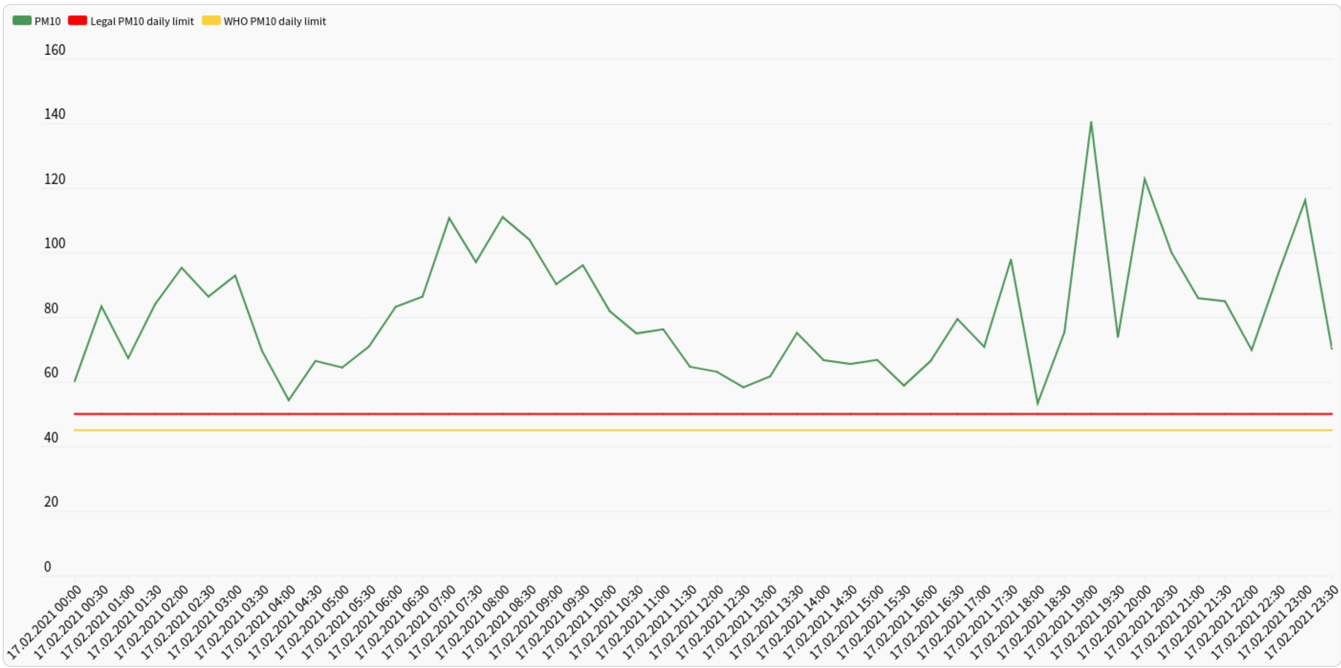

Image 16: *30-minute PM_{10} concentrations (green line) in Novaci between 00:00-23:30 on 17 February 2021. The legal PM_{10} daily limit value (red line) and WHO recommended PM_{10} daily limit (yellow line) do not apply for short-term measurements and are for reference only.*

On most occasions the ash disposal site and the tailings dump are the major sources of PM_{10} particles, although the stacks of the power plant are a significant contributor as well. On some of the most polluted days, a significant portion of the PM_{10} pollution comes from the western side, which indicates that the stoves for household heating in the village are adding to the overall pollution.

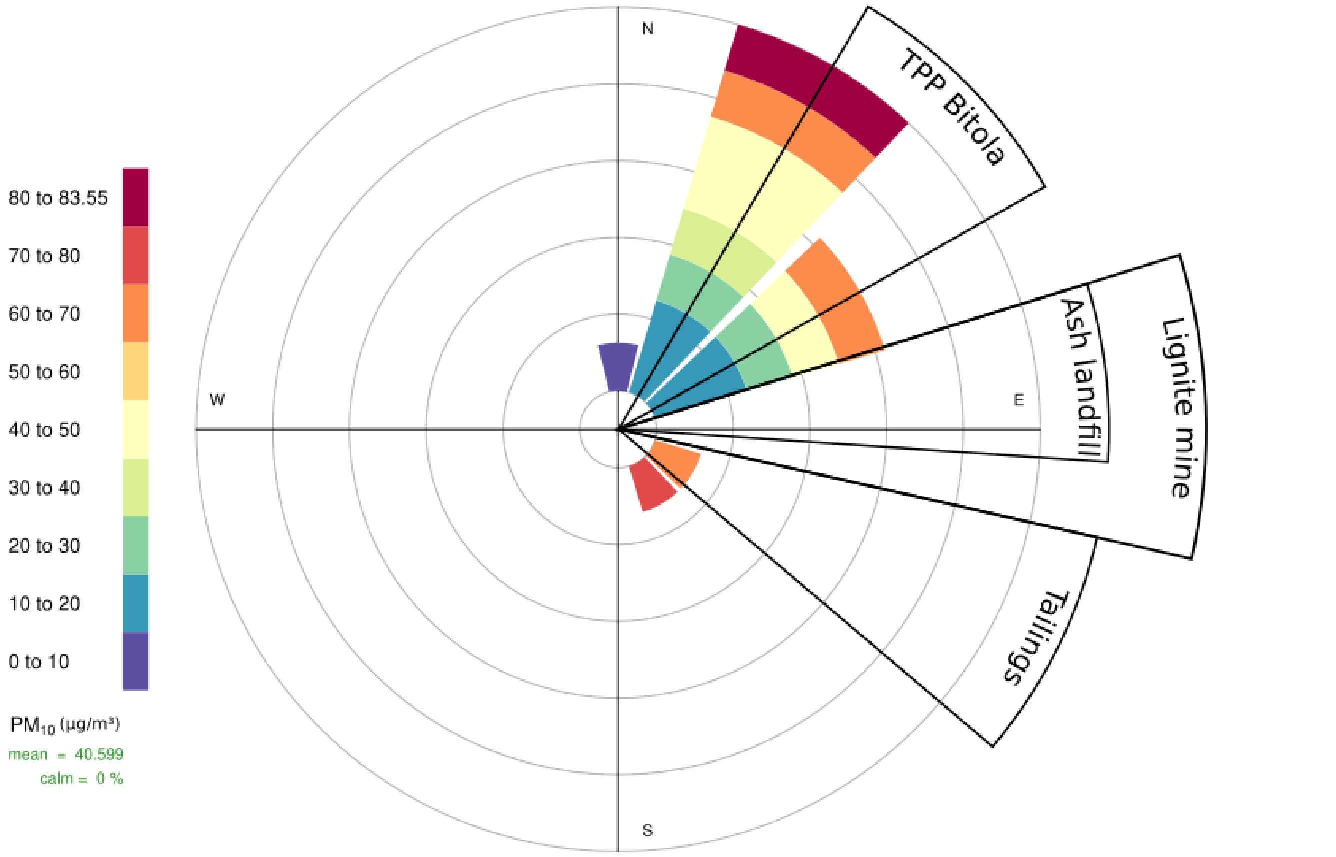

Image 17: *PM_{10} exposure of the monitoring location in Novaci on January 1, 2021, compared to the direction of the major sources of pollution, exceedances per wind direction.*

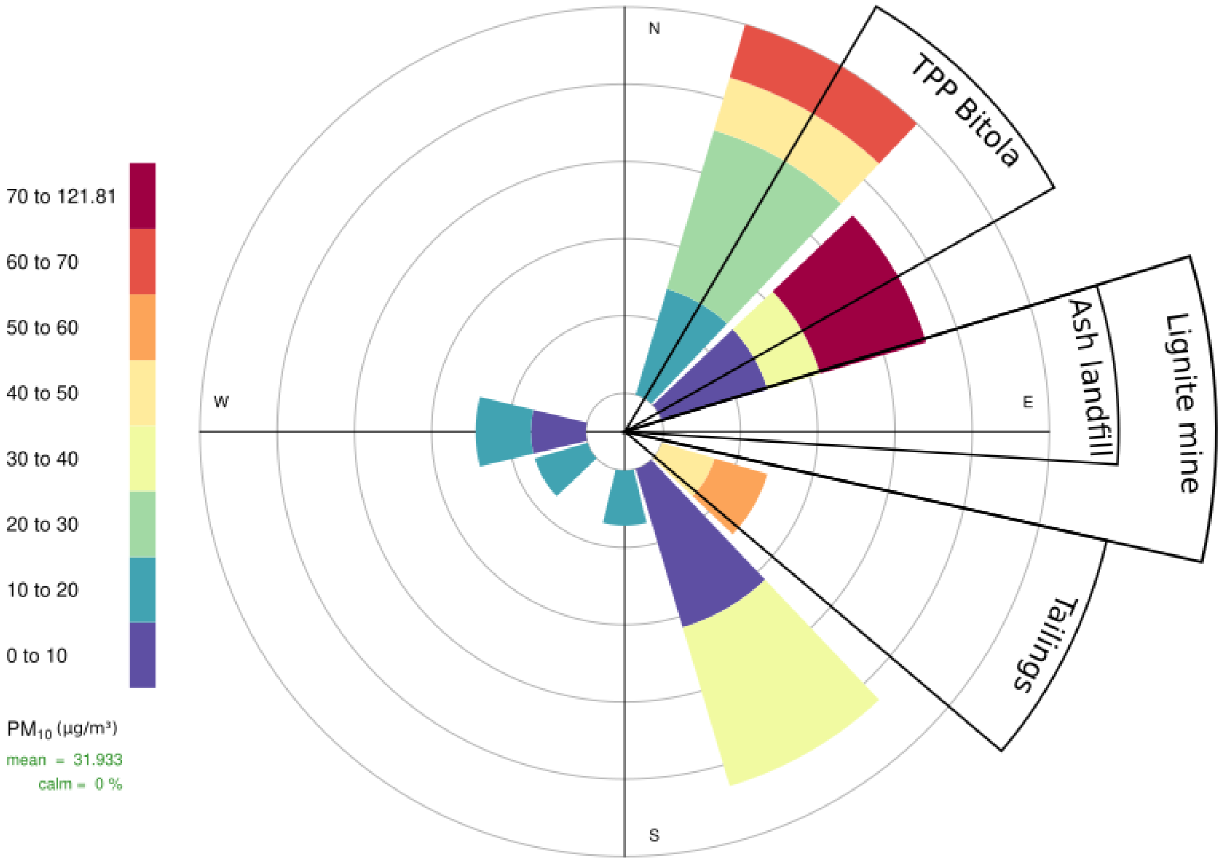

Image 18: *PM_{10} exposure of the monitoring location in Novaci on January 29, 2021, compared to the direction of the major sources of pollution, exceedances per wind direction.*

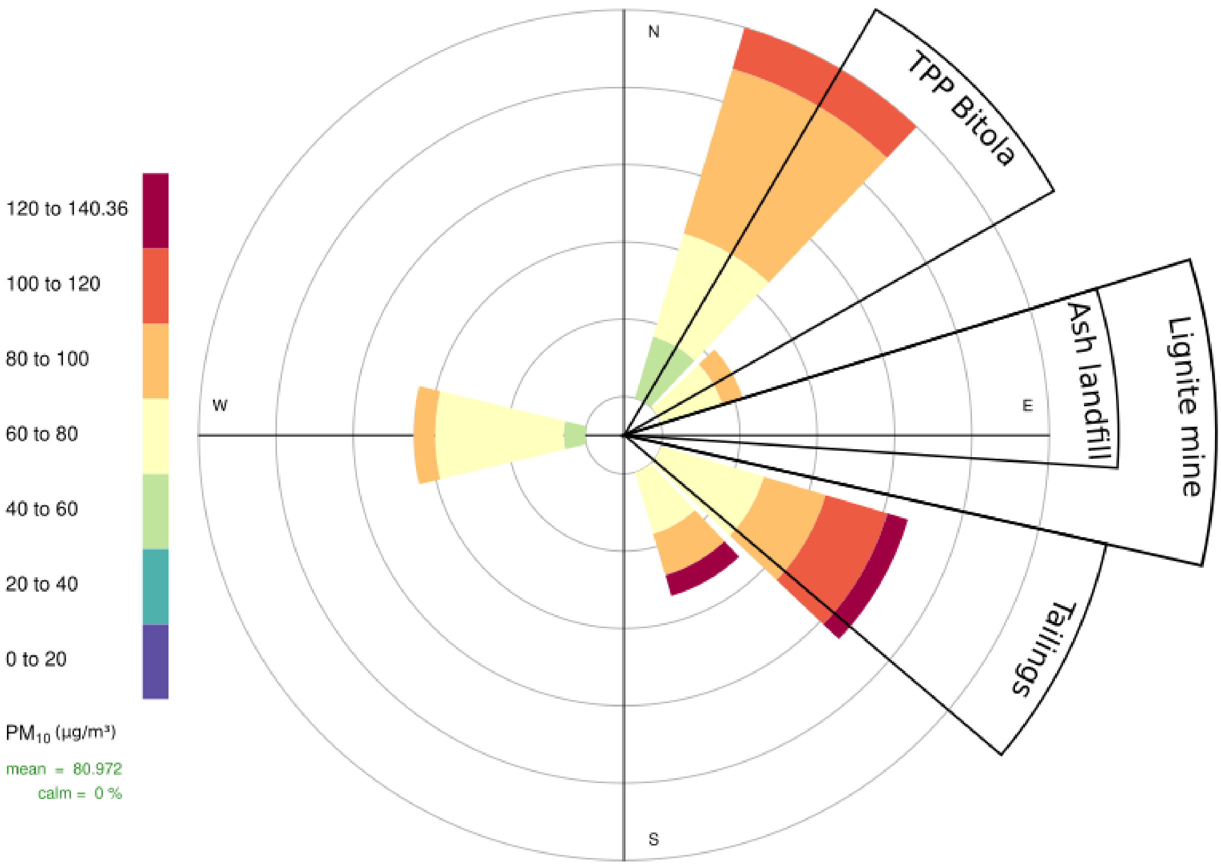

Image 19: *PM_{10} exposure of the monitoring location in Novaci on February 17, 2021, compared to the direction of the major sources of pollution, exceedances per wind direction.*

When the same analysis is replicated for SO2 pollution peaks, the results are similar.

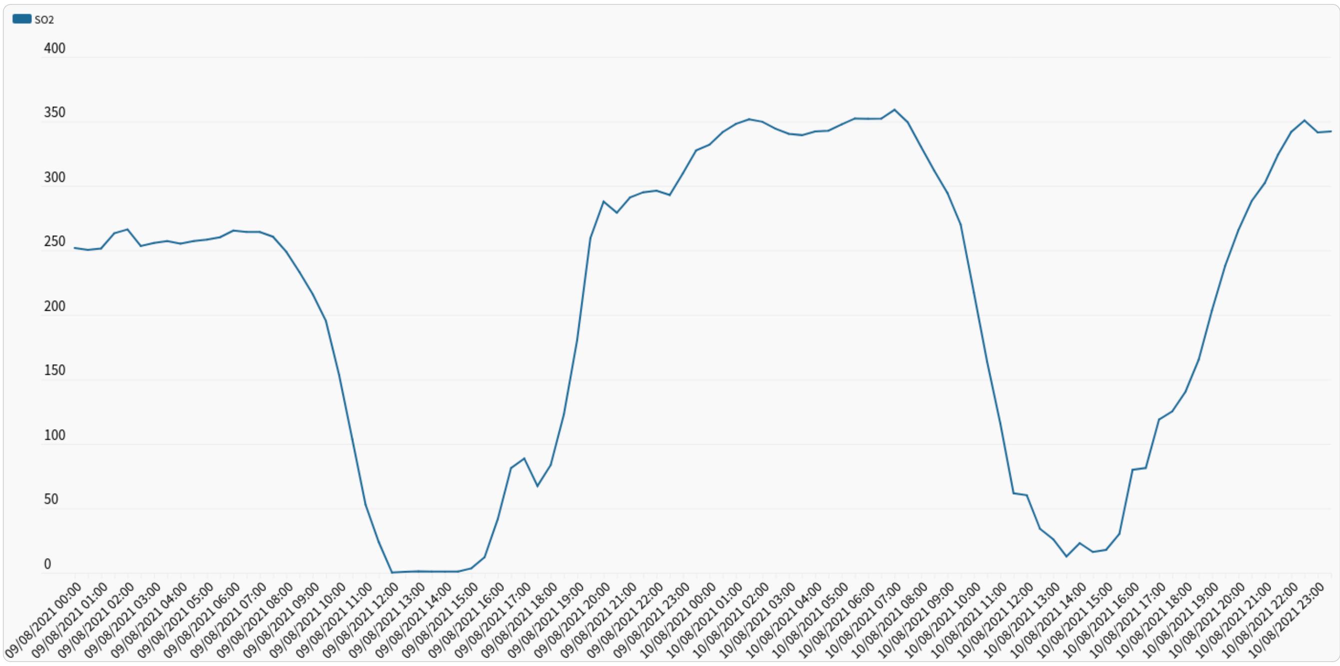

Image 20: 30-minute SO_2 concentrations in Novaci between 9-10.08.2021

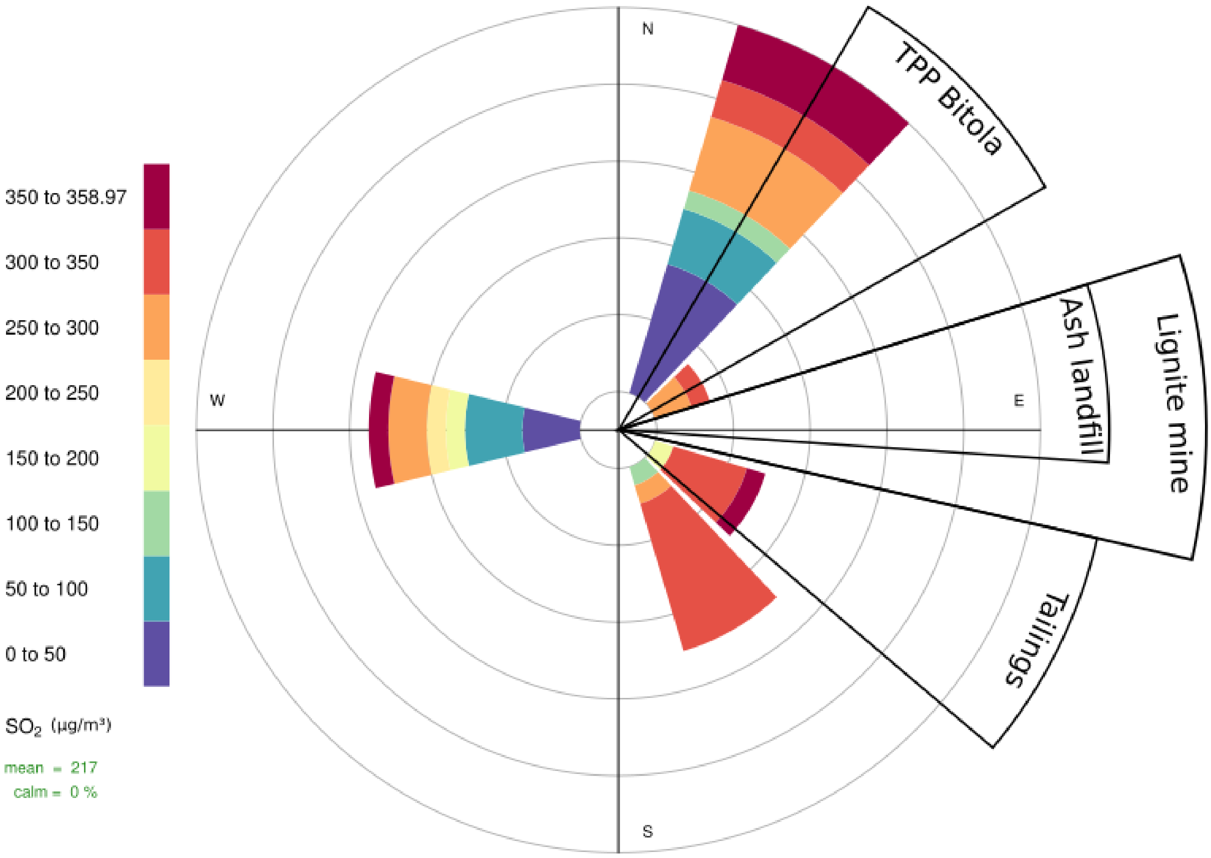

Image 21: SO_2 exposure of the monitoring location in Novaci between 9-10.08.2021 compared to the direction of the major sources of pollution, exceedances per wind direction.

Most of the pollution is again coming from the north-east, where the only possible sources are the stacks of the power plant.

To get a better understanding of the sources of pollution over a longer period of time, the wind direction has to be complemented with wind speed. Wind can have different effects depending on its speed. Higher speeds can cause plumes from tall stacks to be brought down to ground-level or can increase particle suspension from facilities such as ash landfills and open-cast mines, but they can also dilute the concentrations of the gaseous pollutants.

Contribution of the main sources of air pollution in Novaci

By including the variations in wind speed in the analysis, and presenting the results in a polar plot for a one-month period, the general impact of different sources can be observed, not just from the pollution peaks.

The PM_{10} data for the months of January and February 2021, when the limit values were exceeded, show similar results as the pollution roses, but also reveal other insights.

Low concentrations of PM_{10} can be sourced from the entire area, but higher concentrations can be generally attributed to the region east of the monitoring station where the coal facilities are located.

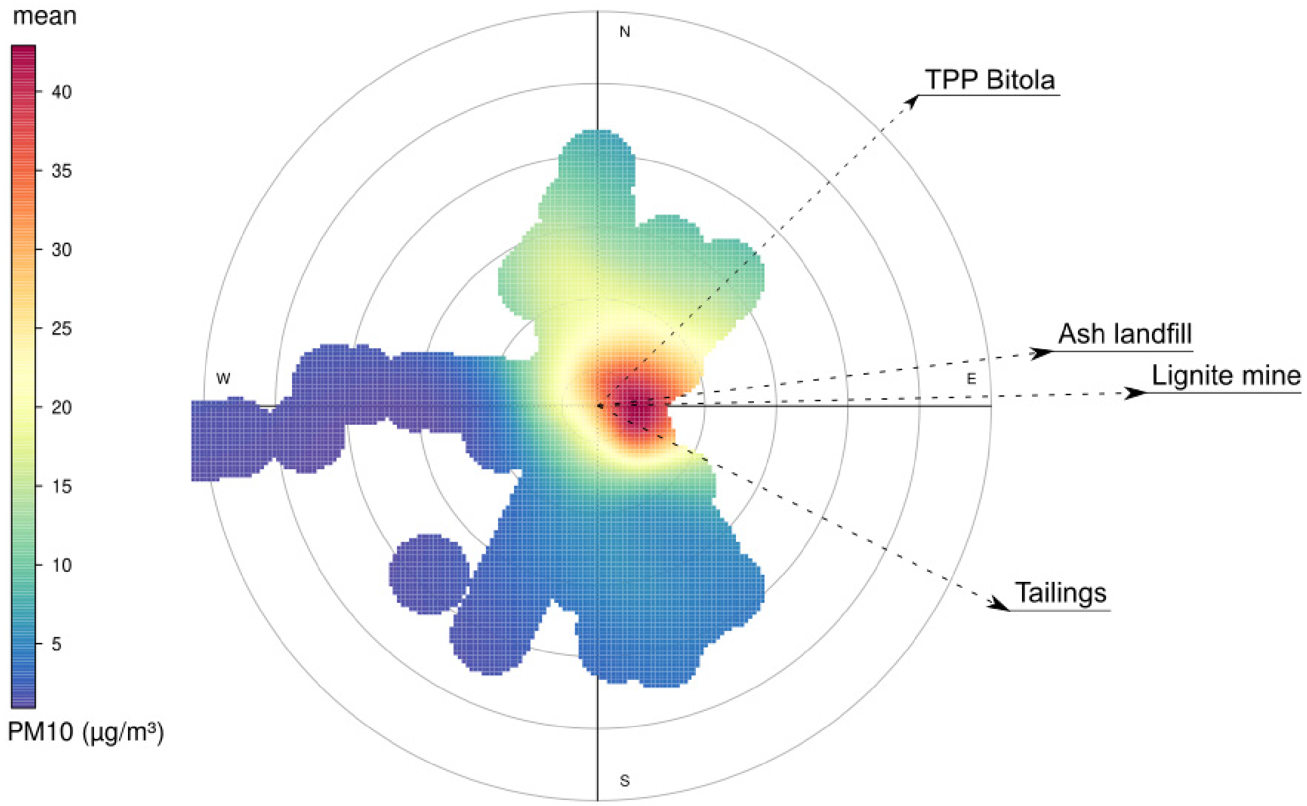

Image 22: *Modelled mean PM_{10} exposure of Novaci during January 2021*

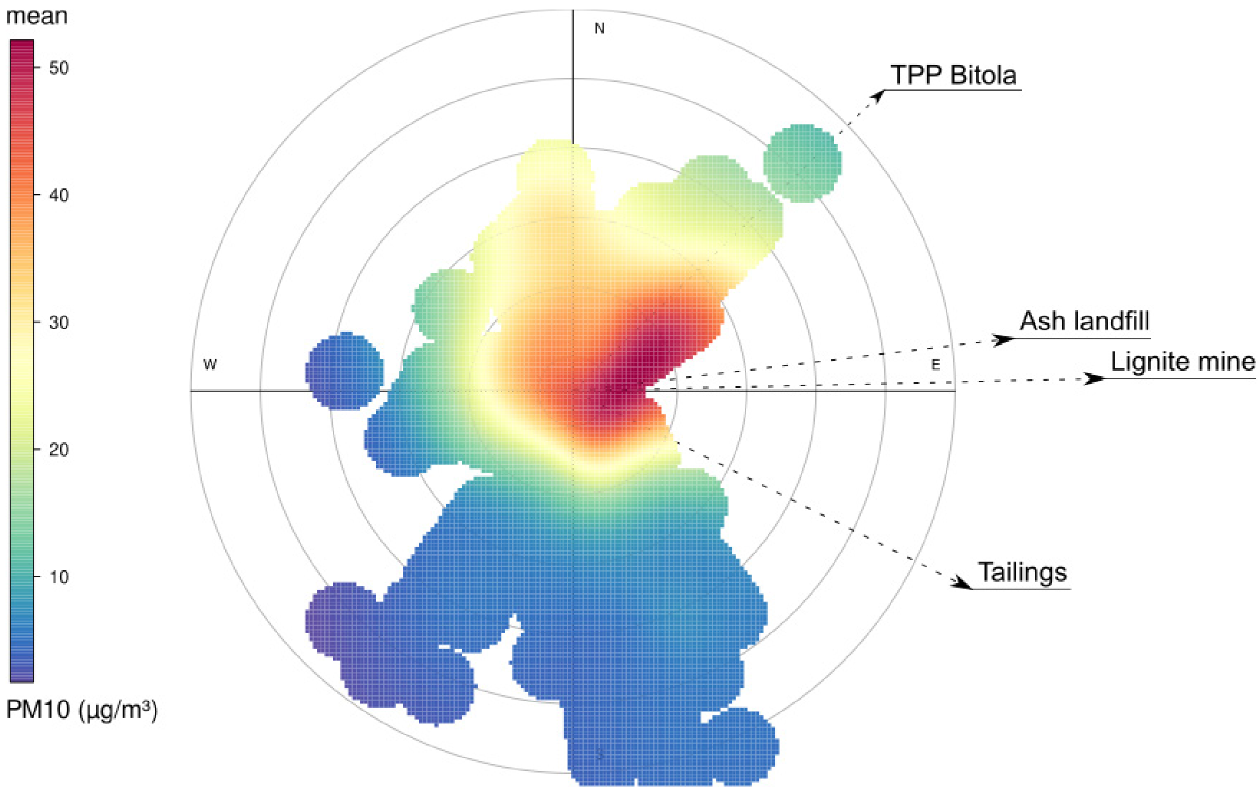

Image 23: *Modelled mean PM_{10} exposure of Novaci during February 2021*

By splitting the data into higher concentrations which mostly contribute to the pollution peaks, and concentrations that are gravitating around the daily limit value, it becomes clearer that the peaks are mostly caused by fugitive emissions from the ash disposal and the mining operations (south-east of the monitoring point), and the high average levels during the period are caused by continuous emissions from the stacks (east and north-east of the monitoring point).

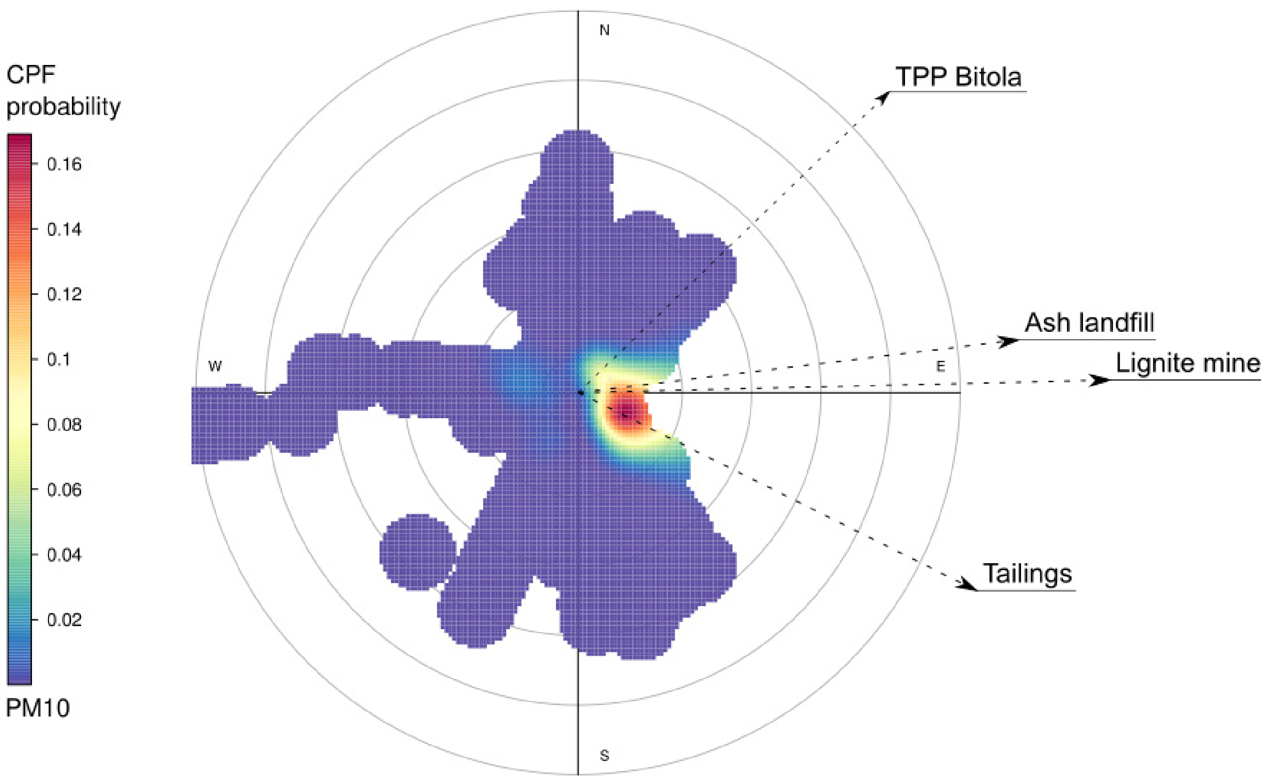

Image 24: *Polar plot of the probability of sources for the highest 5 per cent of the PM_{10} values (95-100 percentile) in January 2021*

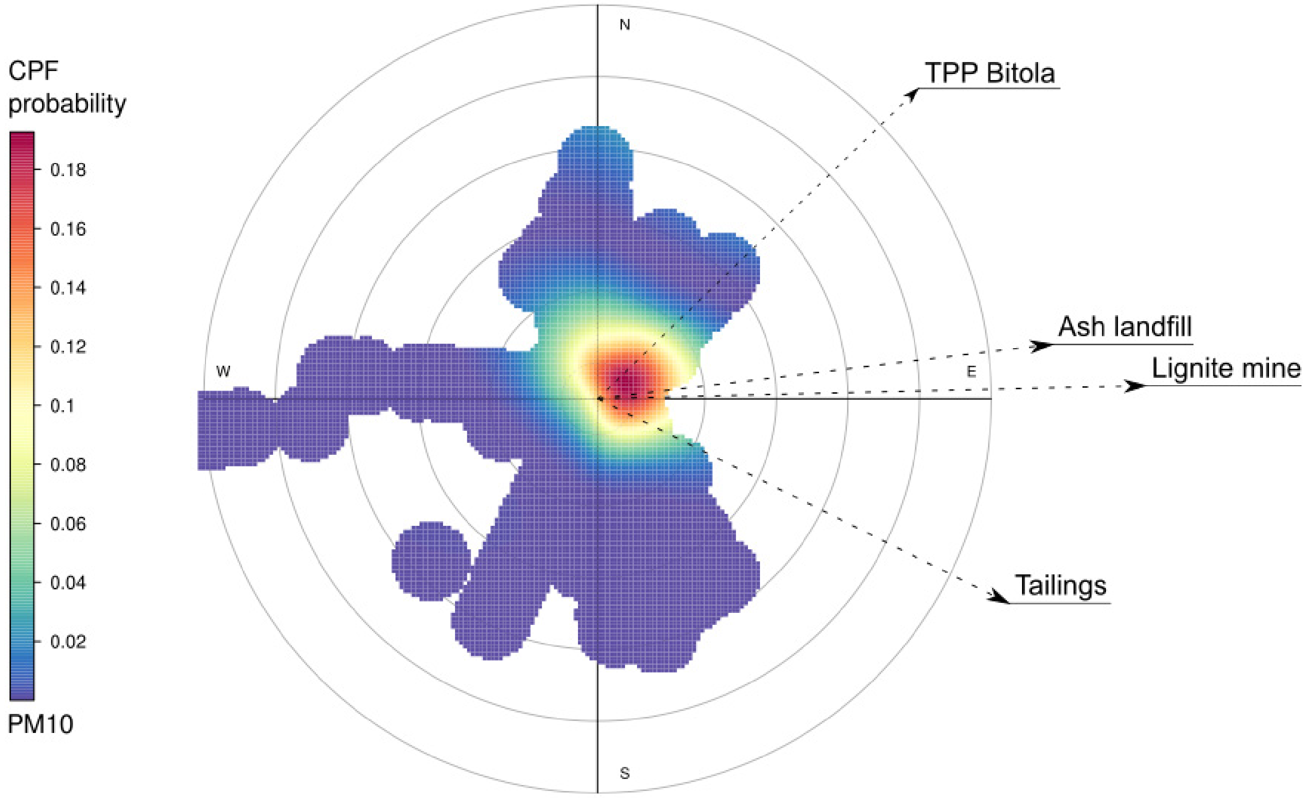

Image 25: Polar plot of the probability of sources for the PM_{10} values between 80th and 95th percentile in January 2021

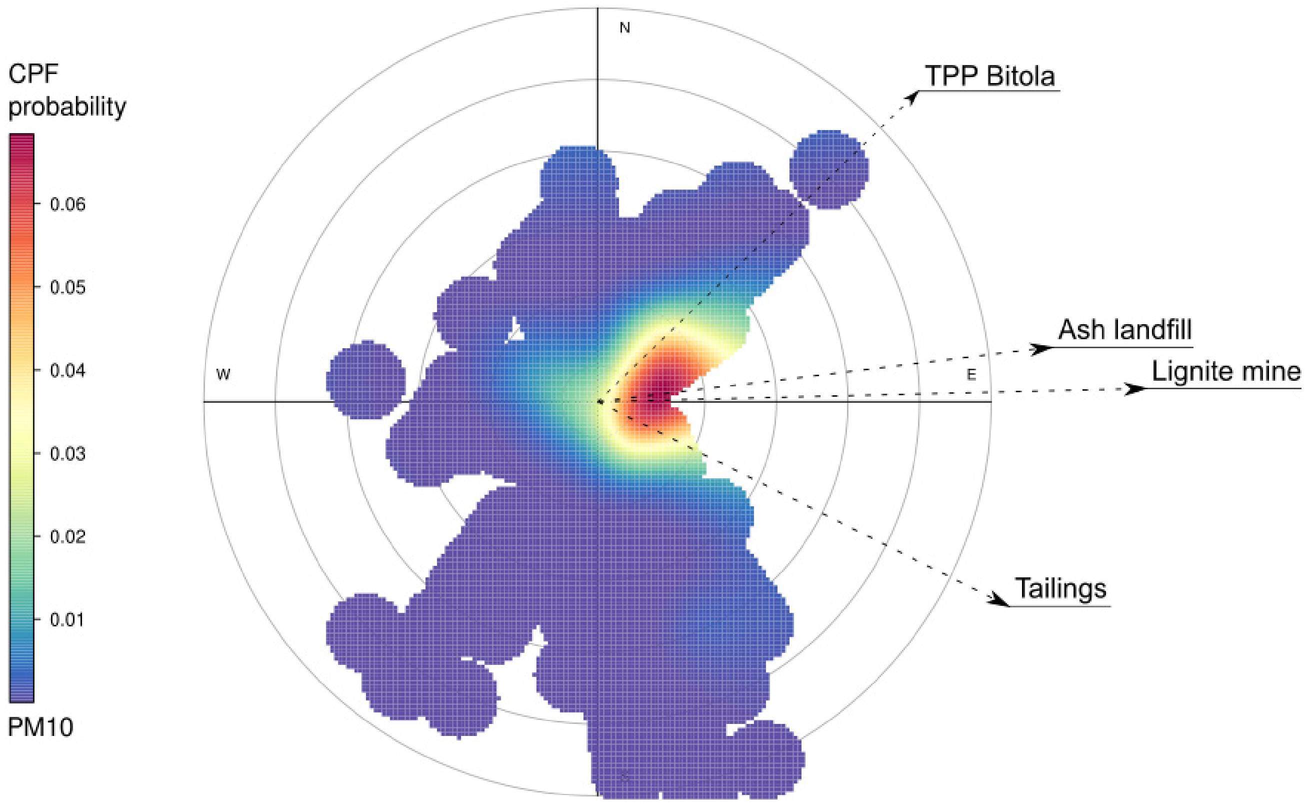

Image 26: Polar plot of the probability of sources for the highest 5 per cent of the PM_{10} values (95-100 percentile) in February 2021

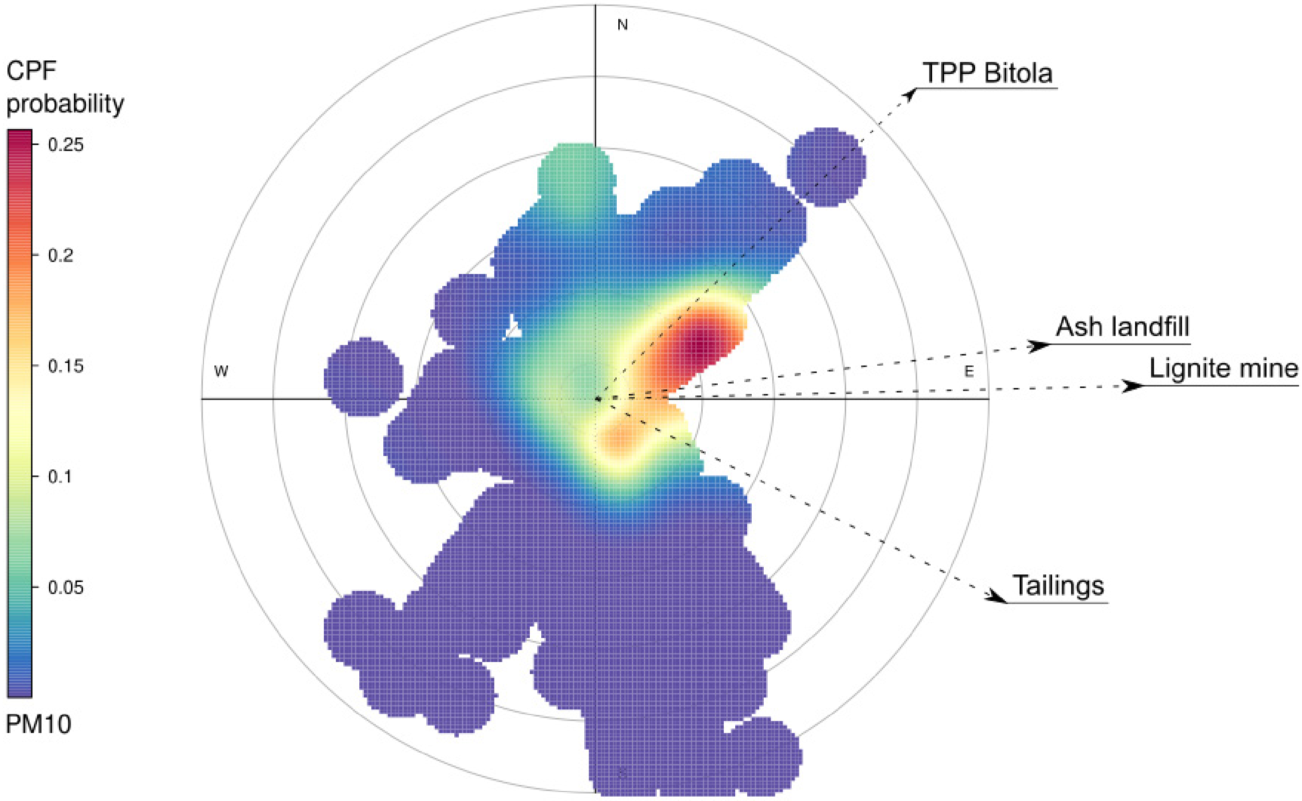

__Image 27:__ Polar plot of the probability of sources for the PM_{10} values between 80th and 95th percentile in February 2021

When the data are split between daytime and night-time, it is visible that higher concentrations happen during night-time. The difference in January is slightly more obvious than in February. This could be caused by meteorological factors, or by a higher workload of the power plant in the evenings and early mornings.

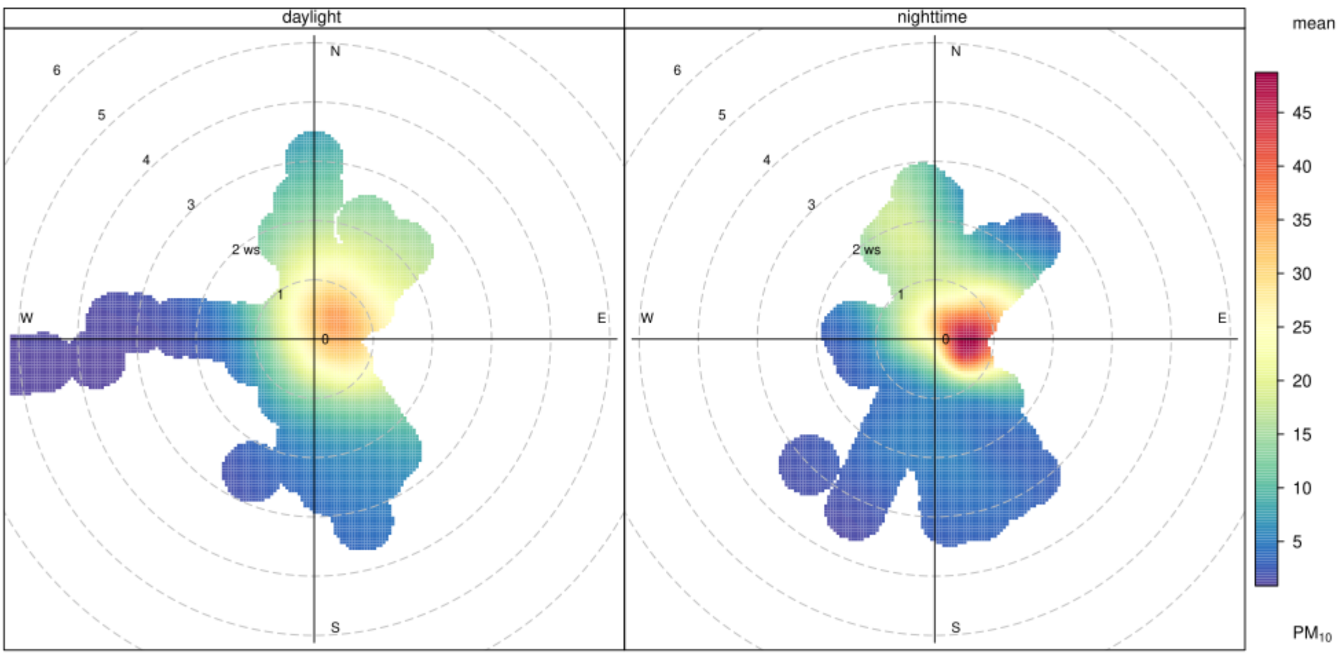

__Image 28:__ Polar plot of the modelled mean PM_{10} exposure in January 2021 during day (left) and night-time (right)

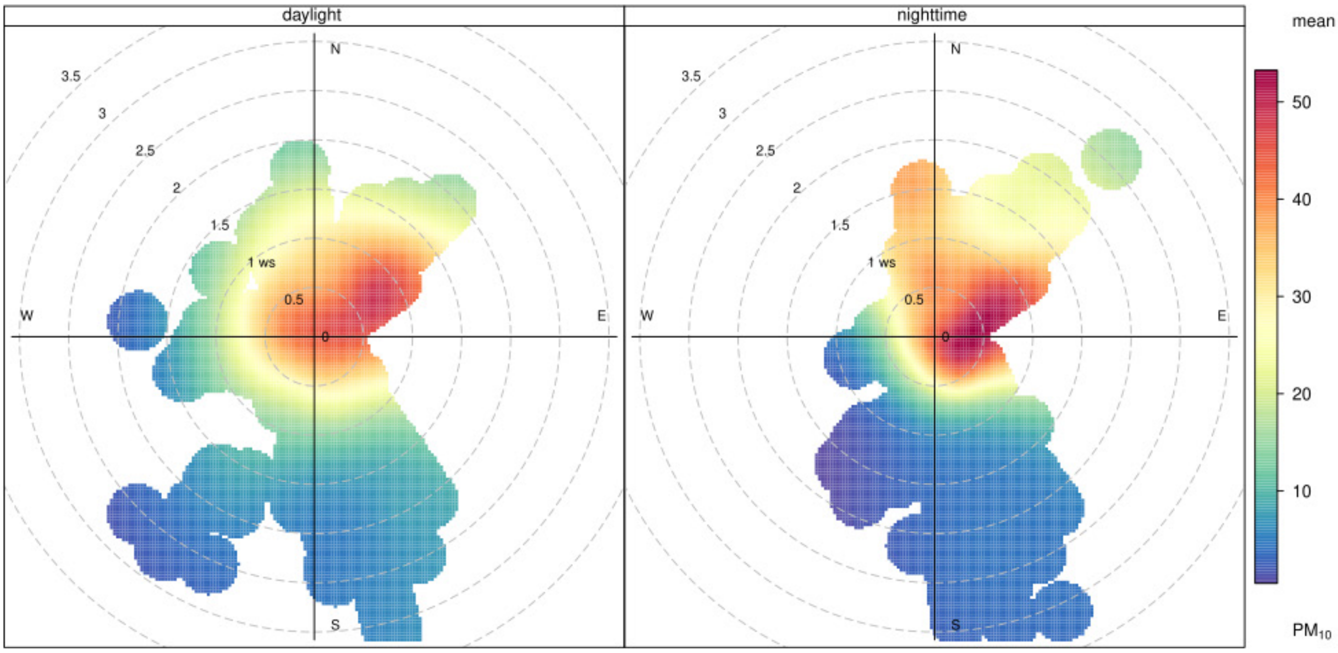

Image 29: *Polar plot of the modelled mean PM_{10} exposure in February 2021 during day (left) and night-time (right)*

When the same methodology is applied to the SO_2 measurements in July and August that had most of the exceedances of the limit value, the results remain similar.

The overall monthly values, however, show that SO_2 pollution comes into the village from multiple directions, although the main direction remains east of the village.

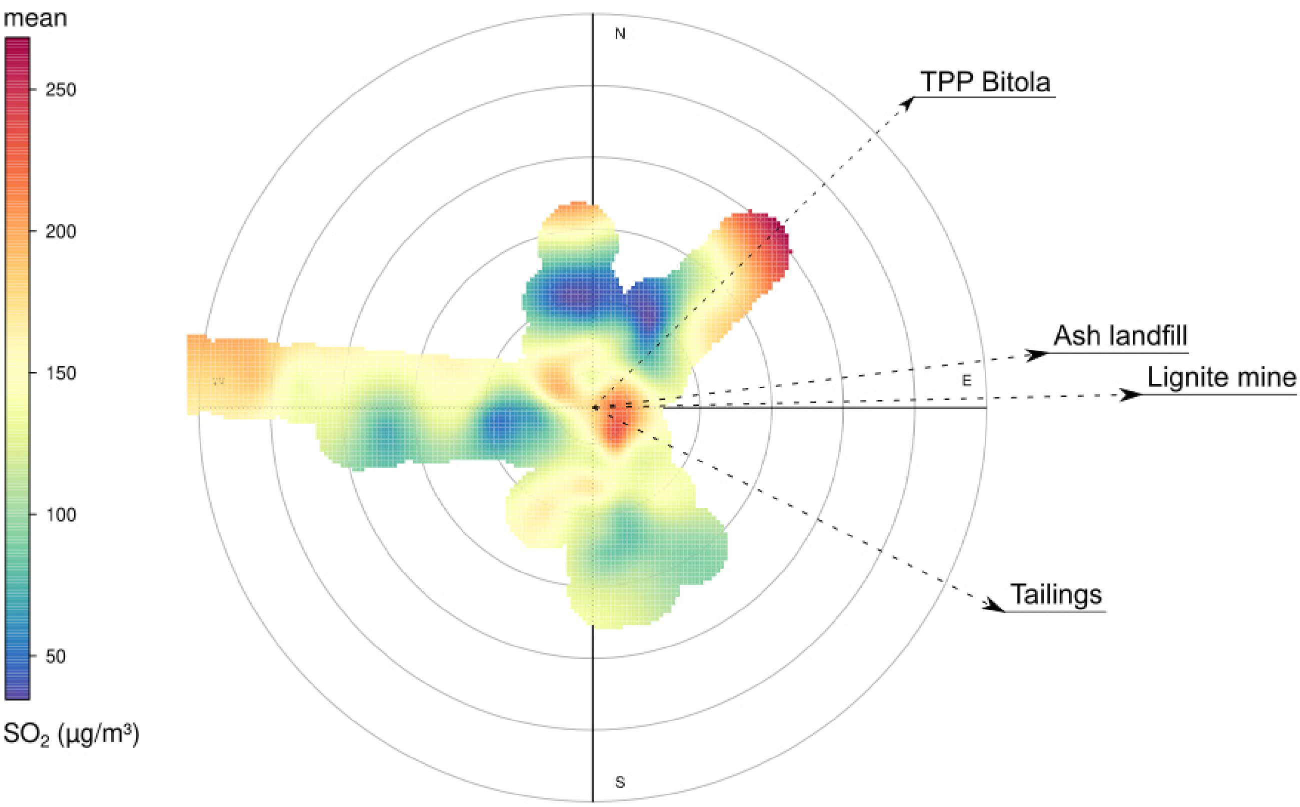

Image 30: *Modelled mean SO_2 exposure of Novaci during July 2021*

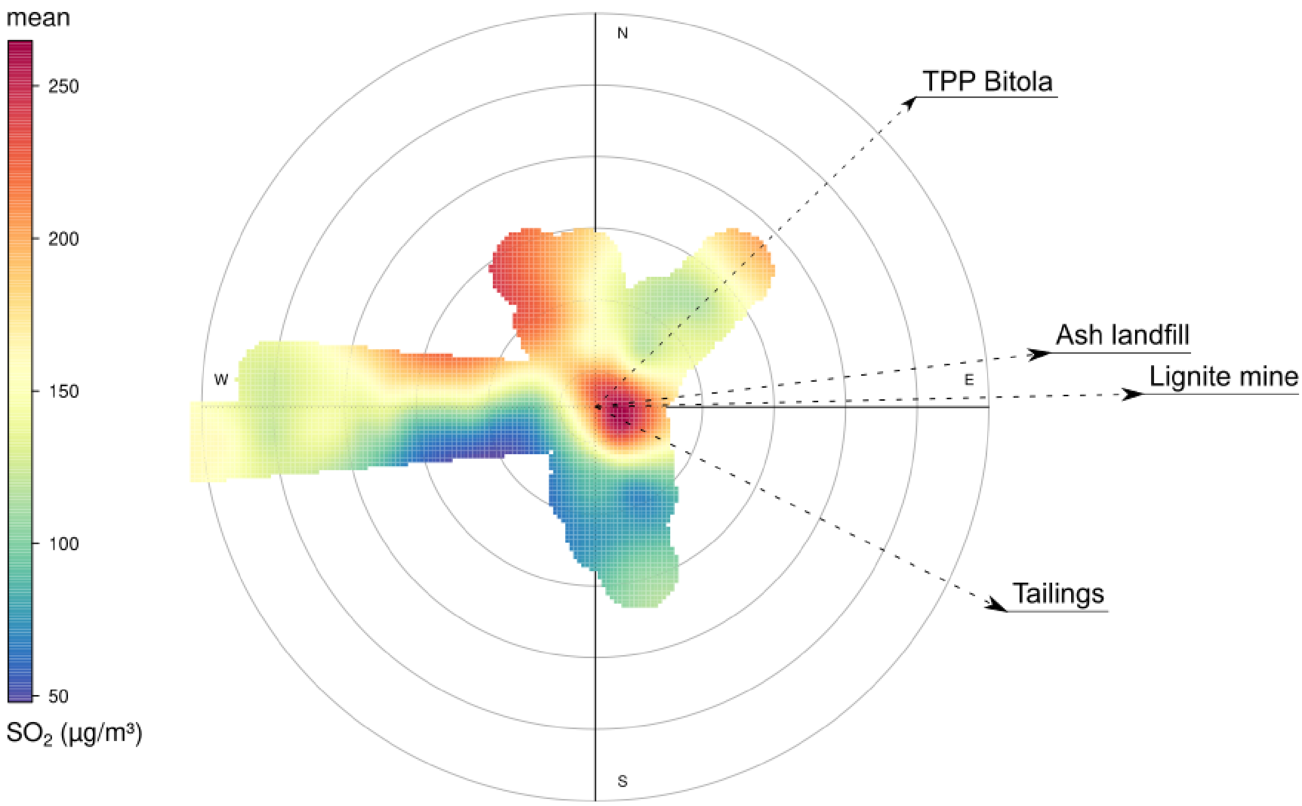

Image 31: *Modelled mean SO_2 exposure of Novaci during August 2021*

When just the highest values of SO_2 concentrations, which can potentially contribute to breaches of the hourly limit value, are taken into account, it becomes more obvious that a source east of the monitoring stations is the dominant cause of the exceedances of the limit values.

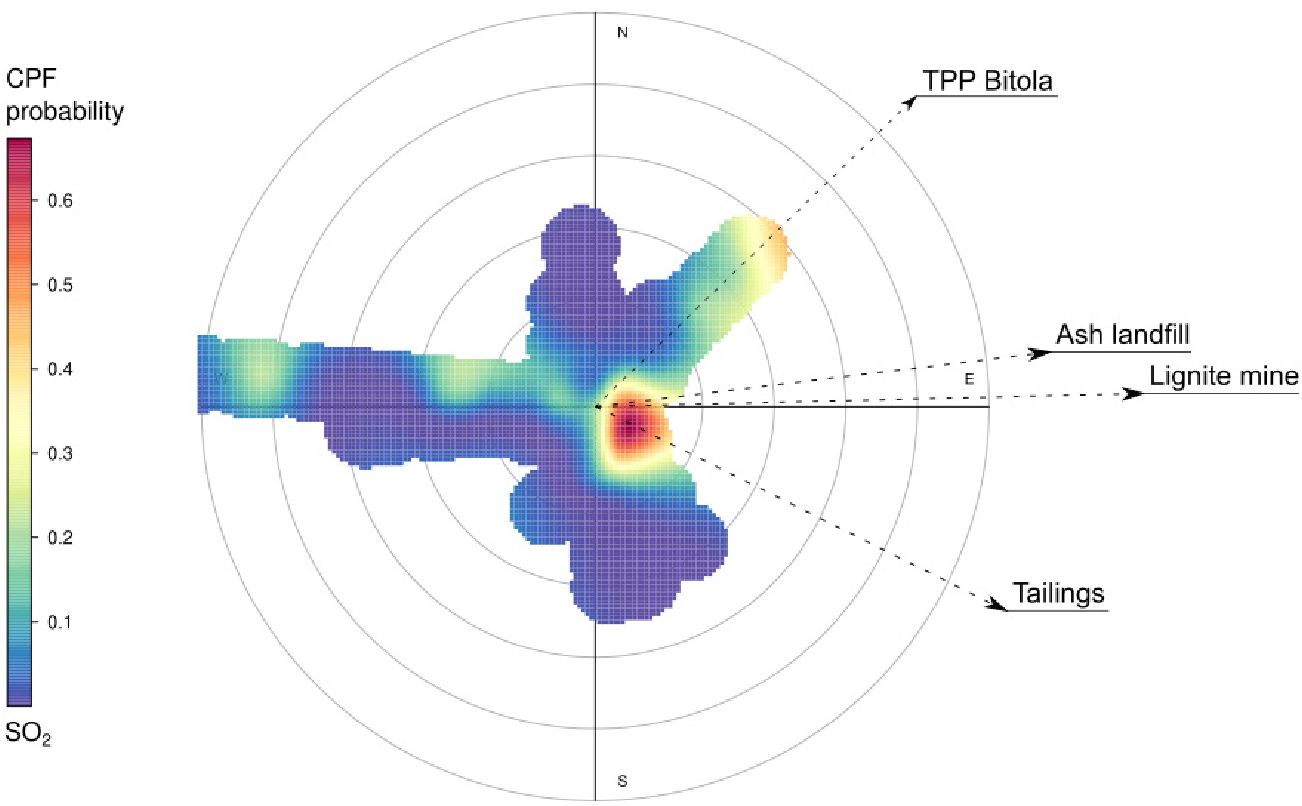

Image 32: *Polar plot of the probability of sources for the highest 25 per cent of the SO_2 values (75-100 percentile) in July 2021*

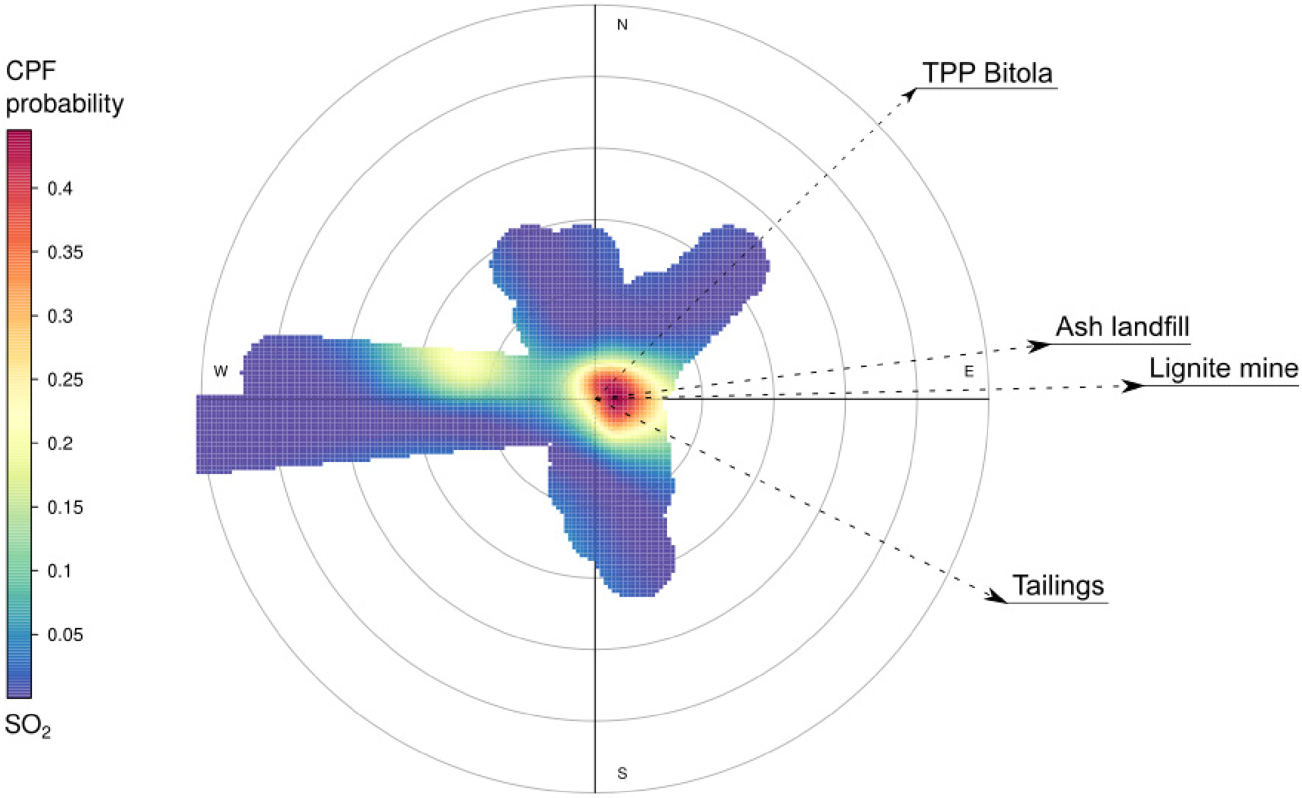

Image 33: *Polar plot of the probability of sources for the highest 25 per cent of the SO_2 values (75-100 percentile) in August 2021*

The unavoidable conclusion based on the overall analysis is that sources of pollution spread out east of the monitoring station are the main contributors to the exceedances of the air quality legal standards.

Because of the siting of the station, which was placed on the edge of the village for easier distinction between the contributions from the village and the coal facilities, it can be said with high probability that the power plant, the ash disposal and the mining operations are the main reason there are exceedances of the limit values in the village.

6. Results of health impact modelling[30]

How does pollution from the Bitola power plant affect the health of nearby citizens?

We used the data from the independent monitoring station placed in the municipality of Novaci for calculating the health impacts on Novaci residents. During the period from January to August 2021 we recorded an average $PM_{2.5}$ level of 16.04 µg/m^3.

$PM_{2.5}$ is linked to premature mortality, and we use it in the health assessment to show how air pollution affects large or small populations.

Mortality in Novaci in 2020

There were 70 deaths (from all causes) recorded in 2020, of which 38 were males, for a population of almost 3,000. Data from the National Health Institute of North Macedonia indicate six cases of chronic obstructive pulmonary disease (COPD) in the age group of 50 to 74, eight hospitalisations for cardiovascular diseases in people of all ages, and eight hospitalisations for respiratory diseases in people of all ages were recorded in inhabitants of the municipality.

COVID-19 mortality as a major consideration when estimating mortality attributable to air pollution in 2020

The death rate in 2020 was higher than in the previous three years. Most likely, the increase is due to the COVID-19 pandemic. The results of the health impact analysis of air pollution acknowledge the major possible bias in 2020 on mortality related to COVID-19.

However, there is evidence[31] that long-term exposure to air pollution is linked to higher rates of COVID-19 mortality, mainly through the mechanism of long-term exposure to air pollution, which means year after year living in a place that is overly polluted and unhealthy.

Air pollution levels due to COVID-19 lockdowns decreased in most of Europe. In North Macedonia, there were decreases in concentrations of PM_{10}, $PM_{2.5}$, NO_2 and O_3 between February and May 2020, compared with the same periods in 2017 and 2018. Pollution levels returned to pre-pandemic levels in May because some of the restrictions were temporarily lifted, but dropped again when they were re-introduced. The most significant declines were for NO_2, whose levels decreased by 5 to 31 per cent[32] mainly because of the decline in transport emissions.

However, in Novaci, despite country-level lockdowns and reduced economic activity, the Bitola power plant's activity continued at comparable levels throughout 2020 and 2021, as did its emissions. Dust emissions in 2020, for example, remained at almost the same level as those in 2018 and 2019, whereas SO_2 emissions were slightly lower than in 2019.[33]

[30] *A detailed explanation of the methodology used for the health impact modelling is given in Annex I.*

[31] *Xiao Wu et al., 'Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study,' Science Advances 6, no. 45 (November 2020).*

[32] *Dimovska et al., 'The Effects of COVID-19 Lockdown on Air Quality in Macedonia,' Open Access Macedonian Journal of Medical Sciences 8, no. T1 (October 2020).*

[33] *CEE Bankwatch Network, Centre for Research on Energy and Clean Air, Comply or Close - How Western Balkan coal plants breach air pollution laws and cause deaths and what governments must do about it, Comply or Close, 2021, 32.*

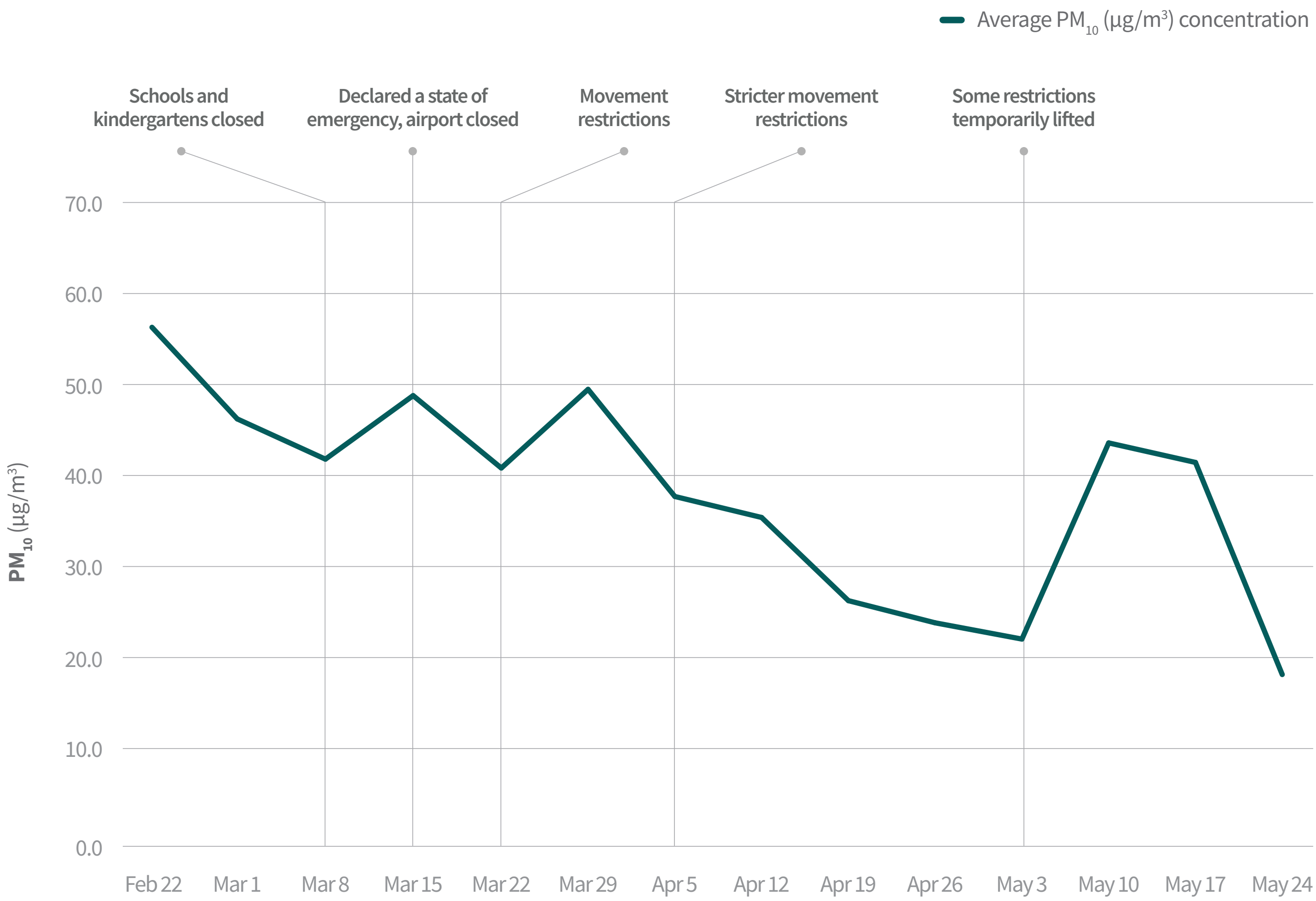

Image 34: *Effects of the implemented Covid-19 restrictions on the weekly average concentration of* PM_{10}

Mortality in Novaci due to ambient PM pollution

$PM_{2.5}$ pollution, whose average concentration during the monitoring period stood at 16.04 µg/m³ in Novaci, is estimated to be responsible for up to 8.43 per cent of mortality among adults. The number of attributable cases[34] in a population of 100,000 individuals would be estimated at 152.

This number is comparable to the mortality cases in some of the most polluted hotspots in the Western Balkans, such as Tuzla, in Bosnia and Herzegovina, where $PM_{2.5}$ pollution is attributed to 101 cases of premature deaths per 100,000 population.[35]

Estimates	Central	Lower	Upper
Estimated attributable proportion of all deaths	6.43%	4.24%	8.43%
Estimated number of attributable cases	4	3	6
Estimated number of attributable cases per 100K population at risk	152	100	200

Table 3: *$PM_{2.5}$ Mortality attribution, 16.04 µg/m³, Novaci (population size 2,952)*

[34] *The number of attributable cases is the number of deaths that can be attributed to air pollution exposure. The number is levelised per 100,000 population so that it is easily comparable in regions with different populations.*

[35] *Vlatka Matkovic, Maida Mulić, Selma Azabagić, and Marija Jevtić, '[Premature Adult Mortality and Years of Life Lost Attributed to Long-Term Exposure to Ambient Particulate Matter Pollution and Potential for Mitigating Adverse Health Effects in Tuzla and Lukavac, Bosnia and Herzegovina](), Atmosphere 11, no. 10: 1107 (October 2020).*

7. Conclusions and recommendations

Based on the results from the official monitoring in Bitola and the independent monitoring done in Bitola and Novaci, it is obvious that air pollution has exceeded the legal limits and WHO guidelines throughout the years.

During the long-term independent monitoring conducted in 2021, significant breaches of the legal limit values for PM_{10} and SO_2 were recorded. Compared to the stricter WHO health protective standards, different pollutants exceeded the recommended values during almost the entire eight months of the monitoring period.

The legal PM_{10} daily limit value was exceeded on 10 days during the monitored period, and the WHO recommended daily limit value on 13 days. The highest recorded daily average was 111 μg/m^3, more than twice as high as the legal limit.

The average $PM_{2.5}$ concentration over the entire monitored period was lower than the legal annual limit, but it was more than three times higher than the WHO recommended for the entire year. The legislation does not establish a daily legal limit, but the limit recommended by the WHO was exceeded on 91 of the monitored days. The maximum recommended number of exceedances is three.

$PM_{2.5}$ has only an annual limit value of 25 μg/m^3 in the legislation. The WHO, however, recommends an annual limit of 5 μg/m^3 and a daily limit of 15 μg/m^3 that must not be exceeded more than 3 times in one calendar year.

The highest recorded concentration in Novaci in 2021 was 107 μg/m^3, more than seven times as high as what is recommended.

SO_2 pollution during the eight-month monitored period exceeded the legal hourly limit value 41 times and the daily limit value 52 times. The recommended WHO limit value was exceeded on 126 of the 243 total days monitored, which means that more than half of the days had air that is more polluted than the health protective recommended limit.

By using different tools for determining the major sources of pollution, it is obvious that the coal-fired power plant, accompanied by an ash landfill, open-cast mine and a tailings dump, is the main contributor that causes the exceedances of the air quality limit values. By limiting emissions from these facilities, air quality in Novaci might be brought within legal standards.

In spite of the lower population density in the municipality of Novaci as compared to other pollution hotspots in the Western Balkans, such as Tuzla in Bosnia and Herzegovina, the estimated health impacts are comparable. $PM_{2.5}$ pollution is responsible for up to 8.43 per cent of the mortality among adults in the municipality. Attributable cases per 100,000 population would be 152 cases.

Recommendations

To the North Macedonian government - particularly the Ministry of Environment and Spatial planning and the Ministry of Economy:

- Install an official monitoring station in a location downwind of REK Bitola in the nearest settlement, as required by the AAQ Directive and national legislation. Alternatively, work with AD ESM (North Macedonia's state-owned electricity company) to make their monitoring results available to the public and in real-time.
- Urgently issue an IPPC permit for REK Bitola.
- Keep operating hours as low as possible to comply with ceilings under the National Emissions Reduction Plan.
- Accelerate the work towards the energy transition and adhere to the coal phase-out date set in the Energy Strategy.
- Improve collaboration with local authorities on the implementation of air pollution reduction measures.
- Begin the just transition planning process, in close cooperation with local decision makers in all municipalities affected by the coal phase-out. This should include ample public consultations as well as cooperation with the initiative for Coal Regions in Transition in the Western Balkans and Ukraine and the international donor community.

To the state-owned electricity company AD ESM:

- Urgently start the procurement procedure for the reconstruction of electrostatic filters in the Bitola power plant.
- Perform monitoring of fugitive emissions from the ash disposal site and the mine and make the results publicly available.
- Install pollution control equipment, such as water sprinklers in mine and the tailings dump.
- Improve the facilities for coal ash storage in a way that will eliminate fugitive emissions.
- Expand the green belt around the entire complex with different kinds of vegetation that would prevent pollutants from travelling longer distances.
- Recultivate depleted lignite mines and closed ash deposits to stabilise the ground and to increase pollution absorption.

To the local authorities in Bitola and Novaci:

- Prepare a joint air quality plan that includes the facilities in REK Bitola and foresees short-term measures directed at the power plant, coal mine and ash disposal sites for periods when air pollution is several times above the legal limit values.
- Increase the share of green spaces in the villages around the power plant.
- Conduct a bottom-up needs assessment process involving large shares of the local population and the business sector to determine the way forward in a coal-free and low-pollution region.
- Join the initiative for Coal Regions in Transition in the Western Balkans and Ukraine and take part in the exchange programme to get inspiration from similar municipalities about moving towards decarbonisation while providing for the local population's well-being.
- Develop a Territorial Just Transition Plan that will guide alternative economic activities in the region and attract future business opportunities.

To the health and medical community:

- Increase the participation of health experts in decision-making processes to ensure that the implementation of preventive measures is up-to-date, and provide input into the development and implementation of clean air activities and plans. Decisions have to be made in a real-time manner. Timely actions will prevent chronic diseases and premature deaths.
- Inform the public about health risks due to air pollution and communicate alerts to your patients and the public when air pollution exceeds healthy levels.
- Highlight the true costs of coal power generation in economic and public health deliberations, consultations and health impact assessments, and advocate for increasing public understanding of how public health will benefit from reducing coal's unpaid health bill.
- Support measures to reduce coal pollution and to develop ambitious, health-protective phase-out plans.

Annex 1 - WHO methodology

Health impacts calculation methodology and public health data on mortality in the municipality of Novaci

In this study, we used AirQ+ software version 2.1.1. The software is a tool for health risk assessment of air pollution developed by the WHO.[36]

AirQ+ is designed to calculate the magnitude of the impacts of air pollution on health in a given population. It handles long- and short-term exposure to ambient air pollution from several pollutants, and long-term exposure to household air pollution from solid fuel use.

AirQ+ can be used for any city, country or region to estimate:

1. How much of a particular health outcome is attributable to selected air pollutants?
2. Compared to the current levels of pollution, what would be the change in health effects if air pollution levels changed in the future, lower than now observed?

Here we estimated the attribution of air pollution to the mortality in the municipality of Novaci, based on the recommendations WHO set in its new guidelines in 2021: the level of pollution would not exceed unhealthy levels set at 5 µg/m^3 for $PM_{2.5}$.

All calculations performed by AirQ+ are based on methodologies and concentration-response functions established by epidemiological studies. The concentration-response functions used in the software are based on the systematic review of all studies available and their meta-analysis.

Pollutant	Pollutant metric	Health outcome	Group	RR (95 % CI) per 10 µg/m^3	Increase in % of health outcome per 10 µg/m^3 increase of pollutant
$PM_{2.5}$	Annual mean	Mortality, all-cause (natural), age 30+ years	A*	1.062 (1.040–1.083)	6.20%

Table 4: *Pollutant–health outcome pairs for which the HRAPIE project recommends concentration–response functions*[37]

CI - confidence interval, RR - relative risk, COPD - chronic obstructive pulmonary disease, CVD - cardiovascular disease, GBD - global burden of disease, $PM_{2.5}$ - particulate matter with an aerodynamic diameter smaller than 2.5 lm, PM_{10} - particulate matter with an aerodynamic diameter smaller than 10 lm

Group A: pollutant–outcome pairs contributing to the limited set of effects but considered already accounted for by summing those with an asterisk

Group A*: pollutant–outcome pairs contributing to the total limited set of effects (the effects are additive)

Group B*: pollutant–outcome pairs contributing to the total extended set of effects (the effects are additive)

Data on population size, mortality and morbidity for Novaci were obtained from the National Statistical Office and from the Public Health Institute of Bitola.

[36] *World Health Organization, AirQ+: software tool for health risk assessment of air pollution, World Health Organization.*

[37] *M.E. Héroux, et al., Quantifying the health impacts of ambient air pollutants: Recommendations of a WHO/ Europe project, International Journal of Public Health 60, no. 5 (2015).*

Major bias and considerations related to COVID-19 mortality in 2020

Mortality numbers varied over the years. In 2020, 70 people died in this small municipality. This was the closest year to the period when we performed air quality monitoring, 2021. The mortality data estimated for 2021 in Novaci take into account the 2020 official mortality numbers, but both years are influenced by an additional COVID-19 mortality rate.

The results of this study account for the major possible bias in the 2020 data regarding mortality, and that is related to COVID-19, which most likely increased the number of deaths. However, some numbers in previous years are comparable to the 2020 ones. Since the population in the municipality is constantly dropping and is estimated to have dropped from 3,549 to 2,952 in the period from 2002 to 2020, the mortality in the pre-COVID period is similar throughout the years.

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
79	73	77	79	78	67	79	75	68	70	65	79	48	45	47	70

Table 5: *Total deaths, all causes, in the municipality of Novaci per year, 2005-2020*

Limitations of AirQ+

The estimates generated by AirQ+ carry some uncertainties, as they rely on information from concentration-response functions, which are based on a number of assumptions. Key assumptions include:

1. models consider ambient air pollution concentration as a proxy indicator of population exposure;
2. calculations do not account for multiple exposure cases or multipollutant scenarios.

Annex 2 - Air quality monitoring and modelling methodology

Monitoring device

We conducted the measurements with a Compact Air Monitoring System (CAMS) produced by Umwelttechnik MCZ GmbH, Germany. The device consists of a gas analyser and dust analyser. It can measure the concentration of TSP, PM_{10}, $PM_{2.5}$, PM_1, SO_2, NOx, O_3 and CO.

The gas analyser uses different measuring principles to monitor concentrations of gaseous pollutants: NDIR (Infrared absorption), NDUV (UV-absorption) TDLS (Tunable Diode Laser Spectrometry) and EC (Electrochemical sensor).

The dust analyser measures the light scattered by individual particles carried in a sample air stream through a laser beam. These measurements are used to determine the particle size (related to the intensity of light scattered via a calibration based on Mie scattering theory) and particle number concentration. Particle mass loadings – PM_1, $PM_{2.5}$, PM_{10} and TSP – are then calculated from the particle size spectra and concentration data, assuming a particle density and refractive index (RI).

The device is equipped with a GPS sensor to provide the exact coordinates of the monitoring location. It is also equipped with a sensor for temperature, relative humidity, barometric pressure, wind speed and wind direction to provide the basic meteorological information necessary to identify sources of dust pollution. It was produced in 2020 and first used for this analysis.

Macro- and micro-siting for monitoring

When choosing the location of the sampling point, we adhered as closely as possible to the requirements of Annex III of the EU's Air Quality Directive (AQD). Our primary objective was to evaluate the impacts of coal facilities (power plants, open-cast mines and ash landfills) on human health in neighbouring settlements, so we used the articles relevant to this objective.

We conducted monitoring in the residential area nearest to the coal facilities, in an area where the highest concentrations are most likely to occur (see AQD, Annex III, Part B, Line (a)). However, we also chose a location that is representative of the whole settlement.

Although every effort is made to do so, we are not always able to place the sampling device downwind of the activity as required by AQD, Annex III, Part B, Line (e). In most cases, in our countries of operation, coal facilities are grouped together and are located in different places around the settlement, in this case mostly spread out to the east of the settlement. It is also common that the most affected communities are not located downwind of industrial activities.

The monitoring device was installed at the closest and most populated settlement, which is not downwind[38] of the coal facilities, but has the highest health implications. It was placed at a location where the source direction of the pollutants can easily be equated with a potential source.

Concerning the microscale siting, the monitoring device is always installed in an open space and the air flow around the inlet is always unrestricted. There was free access of air to the inlet of 360 degrees. The inlet was 2.5 metres above the ground. It was not in the close vicinity of sources that can significantly distort the measurements, and special attention was paid to reducing the direct impacts of automobile traffic on the air samples taken.

[38] *Downwind according to AQ Directive requirements means the direction of the dominant wind direction measured over a longer, usually multi-annual, period of time. Since the monitoring location is west of the power plant, and the dominant wind direction is north-south, in this sense the monitoring location is not downwind of the power plant.*

Comparison of the results with the limit values from the Air Quality Directive and the World Health Organization guidelines

We had set the MCZ CAMS to record measurements every 30 minutes, although it can be set to record them every second if necessary. The collected data were recorded on a memory card in the device, but it is also sent in real time to an online server programmed with a dedicated software for analysing the data. The software then calculates 60-minute, 8-hour and 24-hour mean values, but also records the maximum and minimum values in the period. In addition to this, the software can flag 24-hour averages that cannot be verified because of longer interruptions in the measurements. All data can be accessed in real-time on the server, and it can also be exported for further analysis.

After the completion of the monitoring cycle, which lasted eight months, all collected data were exported and compared to the limit values from the AQD and WHO guidelines. The 24-hour mean values for PM_{10} are compared to the 24-hour limit value given in the AQD. Because there is no 24-hour limit value for $PM_{2.5}$ in the AAQ Directive, the results obtained are compared to the recommended thresholds from the WHO. We publish the results as a line chart, such as the one in image 35. This allows for exceedances of the limit values to be easily identified.

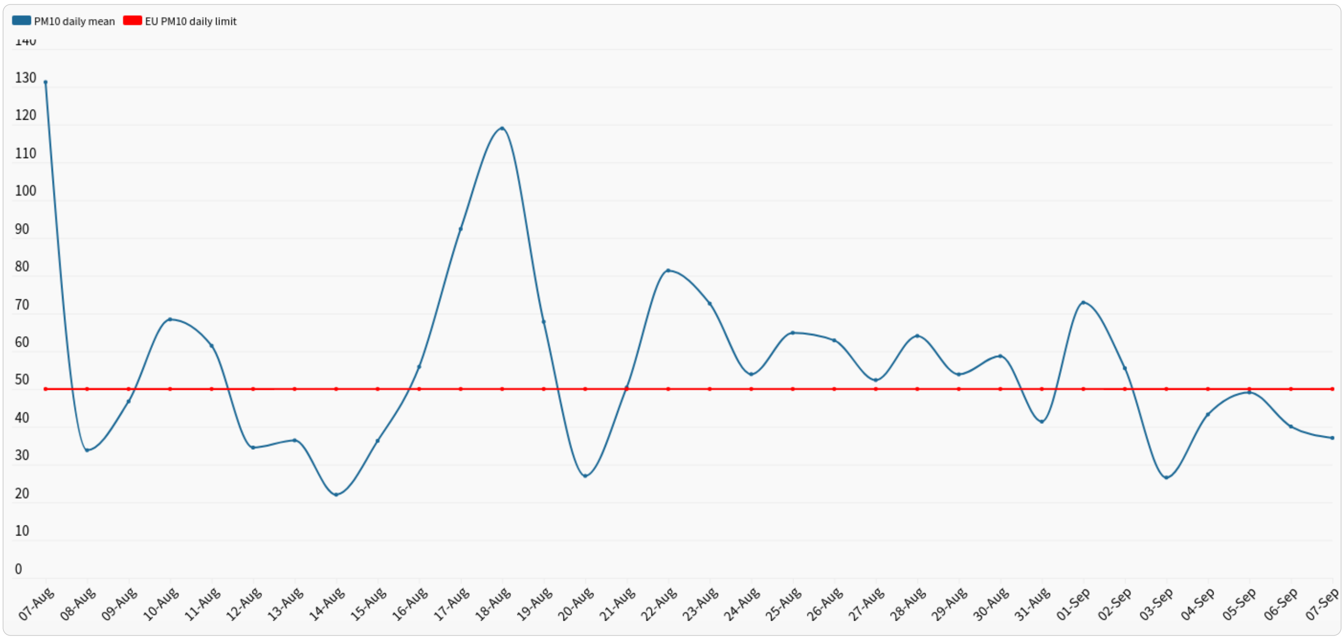

Image 35: *Sample line chart with 24-hour mean values for PM_{10} (blue line) and the daily limit value from the AQ Directive (red line)*

Analysis of the origin of high pollution peaks using pollution wind roses

After we know which days had exceedances, we analyse the short-term values (in this case 30-minute values) for the days with highest values. In this way, we can identify the possible existence of high pollution peaks. These values are also presented as line charts, such as the sample in image 36. The daily limit value is included in these charts for visual reference, but it does not apply to the short-term values.

By using the short-term measurements from the MCZ CAMS and the data on wind direction from the meteorological station, it is possible to approximate the major sources of dust pollution. The measurements are plotted on a pollution wind rose diagram according to the wind direction in the minute when they were recorded. When high pollution measurements are plotted multiple times in the same area of the diagram, there is a high possibility that there is a major source of pollution in that direction.

We display this data set as a pollution wind rose (image 37). This diagram is useful for considering pollutant concentrations by wind direction, or more specifically the number of times a given dust concentration is coming from a certain direction. This type of approach can be very informative for air pollutants, as demonstrated in Henry et al. (2009).[39]

[39] *R. Henry, G.A. Norris, R. Vedantham, and J.R. Turner, '[Source Region Identification Using Kernel Smoothing](#)', Environmental Science & Technology 43, no 11: 4090-4097 (2009).*

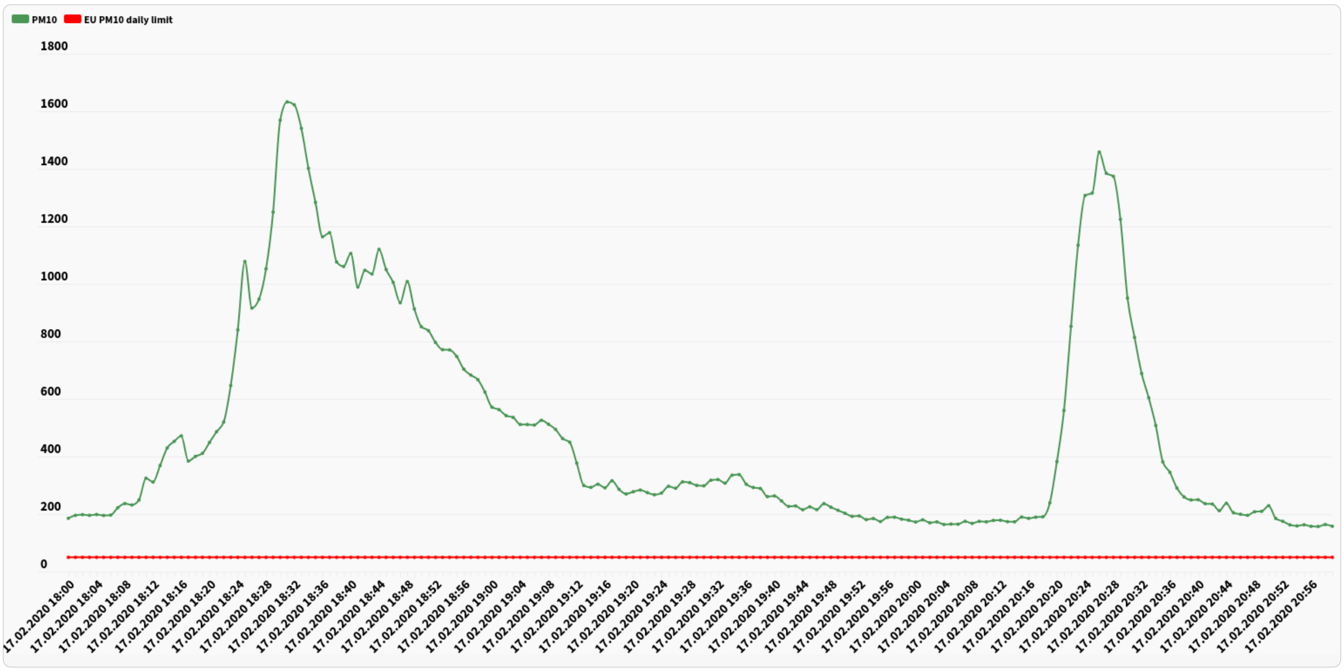

Image 36: *Sample line chart with one-minute values for* PM_{10} *(green line) and the daily limit value from the AQD (red line)*

The coloured wedge segments represent the number of instances when the pollution is coming from that direction and the colours represent the different pollution concentrations in those instances as given on the scale.

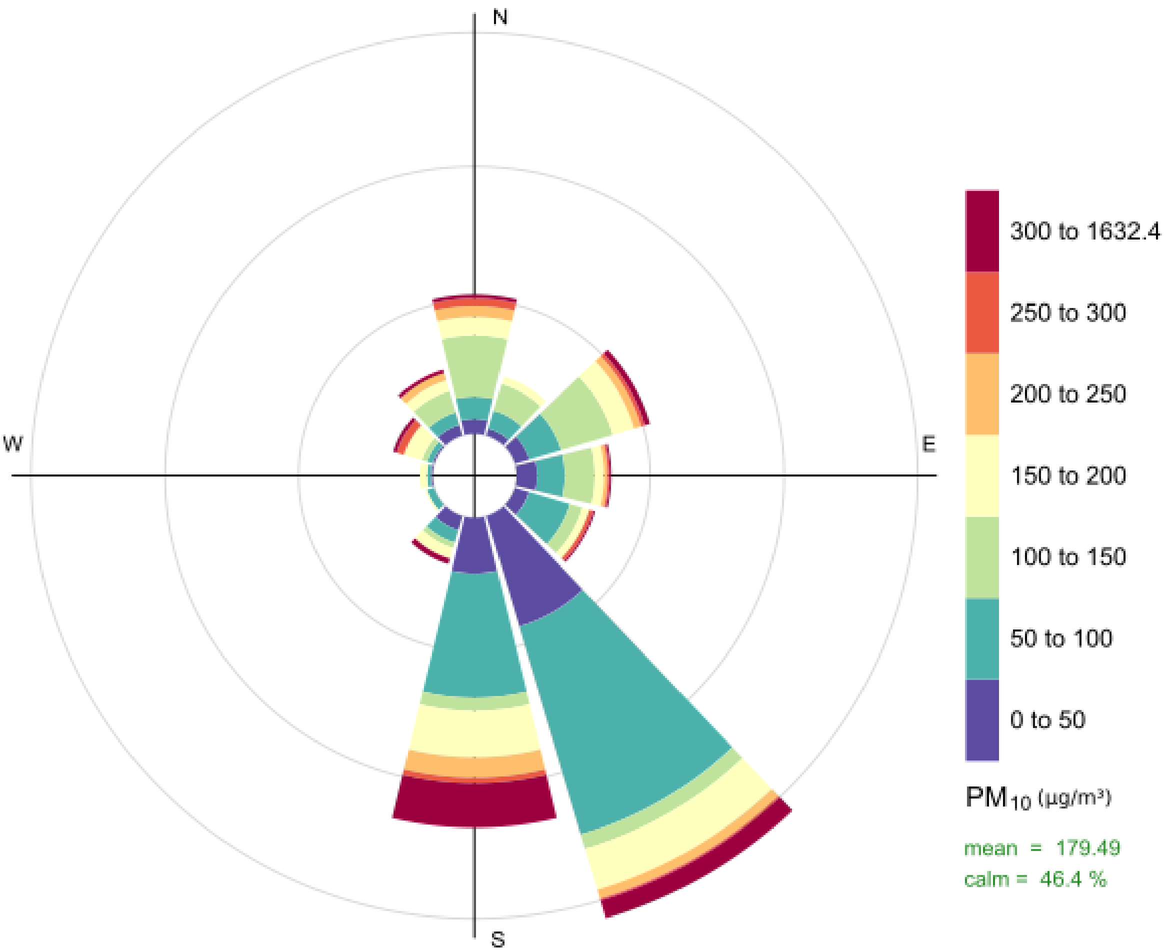

Image 37: *Sample pollution wind rose for the measurements displayed in image 36*

Analysis of the potential sources' influence at a location using polar plots

When there are continuously high values of pollution at a location, identifying the direction of the short bursts of high pollution is not enough to conclude what the underlying cause of the pollution is. Wind can have different effects depending on its speed. Higher speeds can cause plumes from tall stacks to be brought down to ground-level or can increase particle suspension from facilities such as ash landfills and lignite storage, but they can also dilute the concentrations of the pollutants.

This is why the analysis of the measurements must also include a bivariate polar plot of concentrations (image 38). This is a chart that takes into account measurements from a longer monitoring period and takes into account the variations in wind speed to provide insightful information on different sources of pollution, not just the ones that cause the pollution peaks.

These plots are shown as a continuous surface, and surfaces are calculated through modelling using smoothing techniques. The idea of joint wind speed-direction dependence of concentrations has been considered before (see for example Yu et al. (2004)[40]). However, plotting the data in polar coordinates and for the purposes of source identification is first described in Carslaw et al. (2006)[41] and Westmoreland et al. (2007).[42]

These plots have proved to be useful for quickly gaining a graphical impression of potential sources' influences at a location. This function is described in more detail in Carslaw et al. (2006), where it is used to triangulate sources in an airport setting, and Carslaw and Beevers (2013),[43] where it is used with a clustering technique to identify features in a polar plot with similar characteristics.

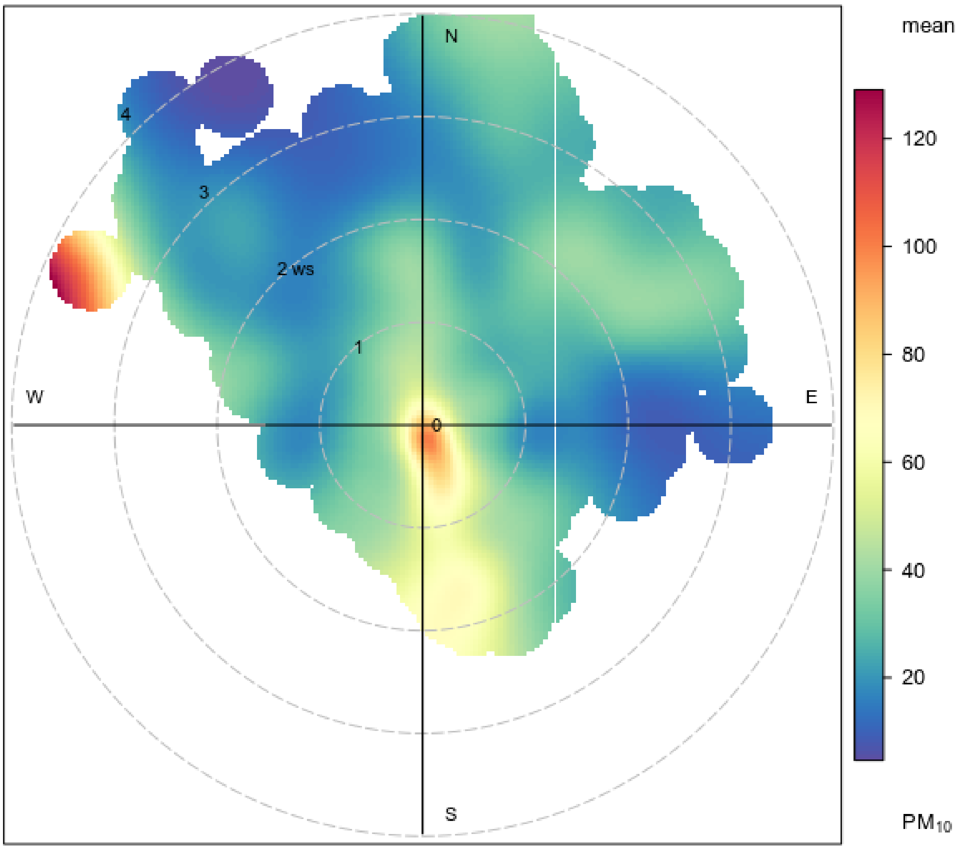

__Image 38:__ Sample bivariate polar plot of concentrations

40 *K. Yu, Y. Cheung, T. Cheung, and R. Henry, 'Identifying the impact of large urban airports on local air quality by nonparametric regression', Atmospheric Environment 38, no 27: 4501-4507 (2004).*

41 *D. C. Carslaw, S.D. Beevers, K. Ropkins, and M.C. Bell, 'Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport', Atmospheric Environment 40, no. 28: 5424-5434 (2006).*

42 *E. J. Westmoreland, N. Carslaw, D. C. Carslaw, A. Gillah, and E. Bates, 'Analysis of air quality within a street canyon using statistical and dispersion modelling techniques', Atmospheric Environment 41, no. 39: 9195–9205 (2007).*

43 *D. C. Carslaw and S. D. Beevers, 'Characterising and understanding emission sources using bivariate polar plots and k-means clustering', Environmental Modelling & Software 40: 325–329 (2013).*

Analysis of the probability of sources for different pollution values using polar plots with conditional probability function

When there are different sources identified with the pollution wind rose and with the bivariate polar plot, the next step is to analyse the set of high pollution values separately from the rest of the values. For this purpose, a statistic called the conditional probability function (CPF) is introduced.

The CPF was originally used to show the wind directions that dominate a (specified) high concentration of a pollutant and showing the probability of such concentrations occurring by wind direction[44]. However, these ideas can also be applied to bivariate polar plots. CPF analysis is very useful for showing which wind direction and wind speed intervals are dominated by high concentrations and give the probability of this occurring. A full explanation of the development and use of the bivariate case of the CPF can be found in Uria-Tellaetxe and Carslaw (2014),[45] where it is applied to monitoring data close to a steelworks.

For example, considering the interval between the 95th and 100th percentile of the collected measurements displays only the possible sources of the highest five percent of the values (image 39). Considering the values that are in the 80th to 95th percentile interval displays values that are high enough to cause exceedances of the 24-hour values, but are not related to the high pollution peaks (image 40).

This helps to show some potentially important differences between the sources that could have been easily missed and can therefore help to build a more complete understanding of source contributions.

In the sample images, it is apparent that sources in the south are only relevant for the higher pollution values, but are completely irrelevant for the 80th to 95th percentile interval. At the same time, the sources in the north-west are the major contributor in the lower percentile interval.

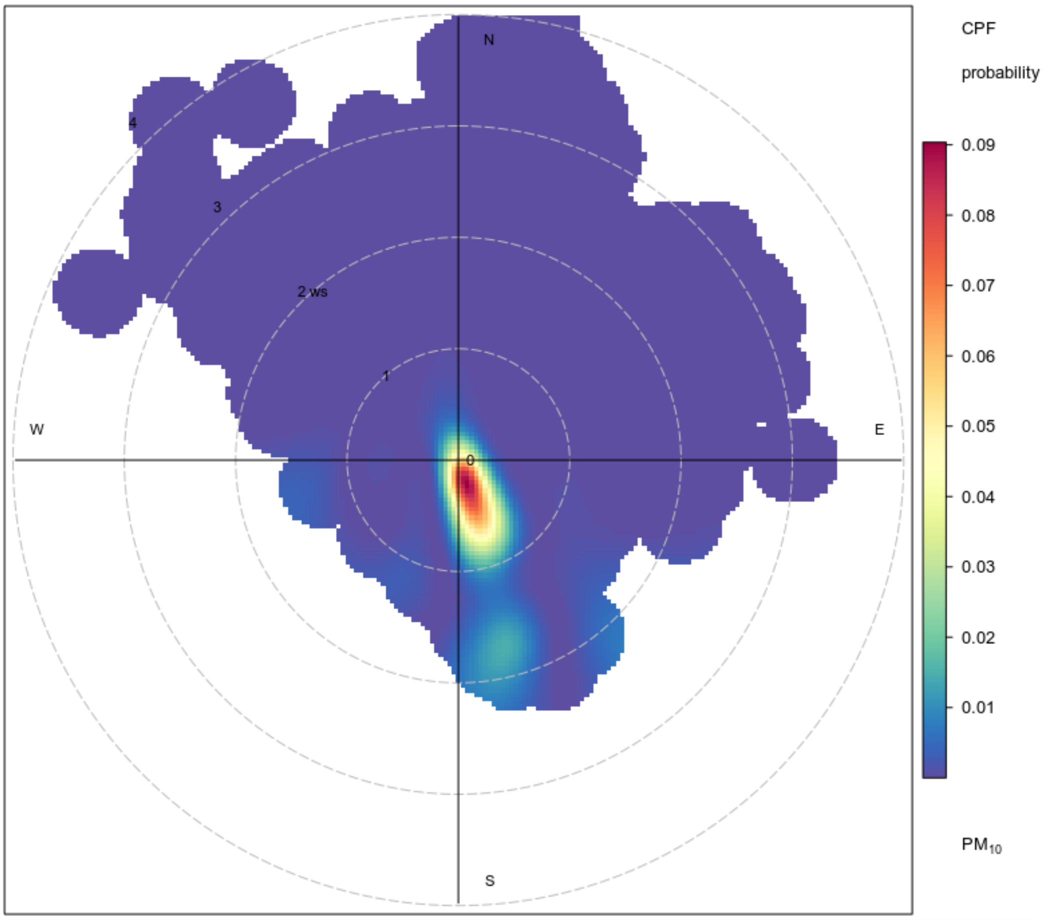

Image 39: *Sample conditional bivariate probability function for the 95th to 100th percentile interval*

[44] *L. L. Ashbaugh, W. C. Malm and W. Z. Sadeh, 'A residence time probability analysis of sulphur concentrations at Grand Canyon National Park', Atmospheric Environment 19, no. 8: 1263–1270 (1985).*

[45] *I. Uria-Tellaexte and D. C. Carslaw, 'Conditional bivariate probability function for source identification', Environmental Modelling & Software 59: 1–9 (2014).*

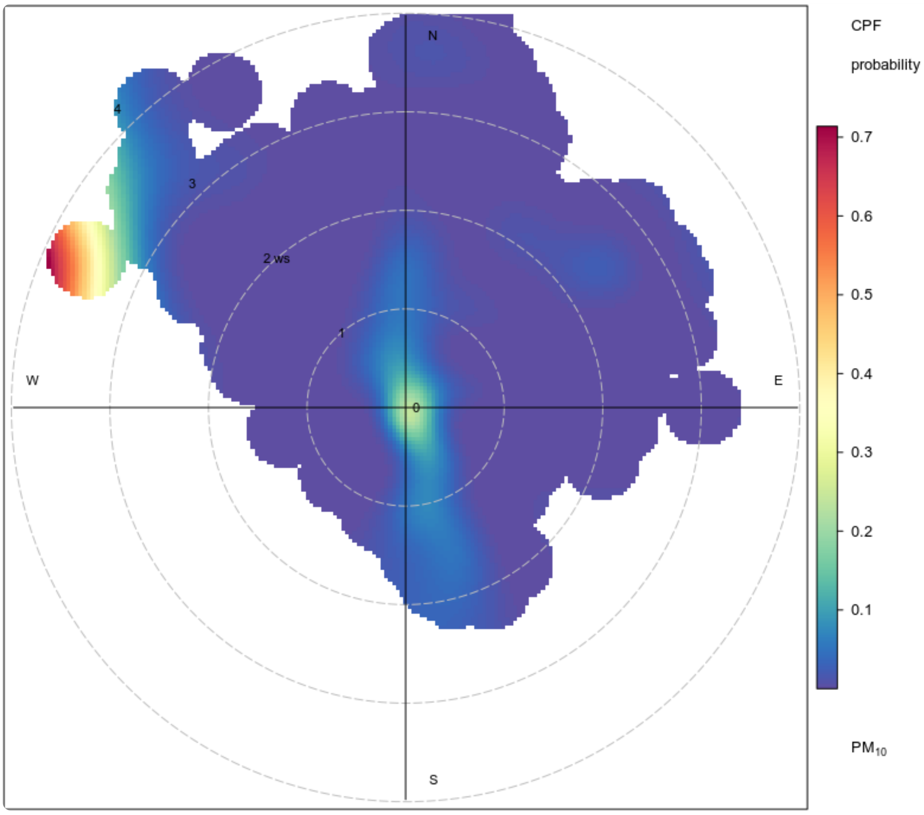

Image 40: *Sample conditional bivariate probability function for the 80th to 95th percentile interval*

Analysis of the differences between daytime and night-time pollution values using polar plots

Another useful analysis in our work is looking into distinctions between daytime and night-time. This is particularly useful if in the previous steps there is an obvious pattern of high pollution peaks occurring during a certain time of the day. The previously mentioned bivariate polar plot of concentrations can be used here, to separately display the possible sources during day and night (image 41).

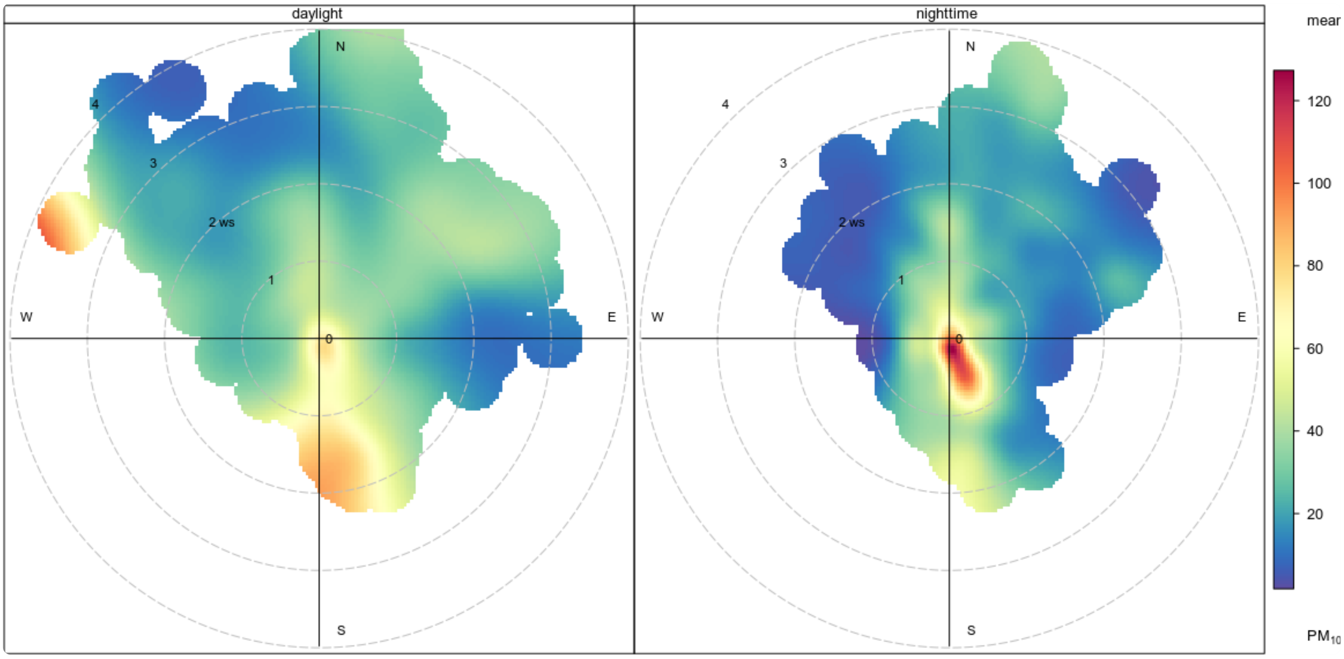

Image 41: *Sample bivariate polar plot of concentrations for the daytime values (left) and night-time values (right)*

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