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Causes And Consequences Of Air Pollution In North Macedonia

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Independent
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Question

Provide an overview of past studies of the causes and consequences of air pollution in North Macedonia?

Contents

1. Summary

This rapid literature review collates available evidence on the causes and consequences of air pollution in the Republic of North Macedonia (here after North Macedonia). It draws on a diverse range of sources from multiple academic disciplines and grey literature. The literature highlights that North Macedonia is considered to have some of the worst air quality in the West Balkans, and consequently some of the worst globally. Air pollution is a significant problem in North Macedonian cities and urban centres with exposure to high levels of particulate matter (PM) a particular issue. The $PM_{2.5}$ size fraction is the focus of many air pollution studies because it is associated with a range of adverse health outcomes, it is also the focus of this review.

This review identifies a limited but expanding evidence base discussing air pollution in North Macedonia. Studies are principally focussed on the capital city (Skopje) and ambient (outdoor) air pollution. There is a limited literature that discusses air quality issues outside of the capital and a dearth of evidence on household (indoor) air pollution. The report is structured as follows:

- Section two provides a broad overview of air pollution in North Macedonia, identifying available studies and analyses of air quality data.
- Section three provides an illustrative account of causes (more commonly referred to as sources) of air pollution and a wider reflection on factors that may influence the levels of air pollution in North Macedonia.
- Section four provides an overview of some of the consequences of air pollution in North Macedonia, grouped according to health, economic and political impacts.

Key Messages emerging from this literature review include:

Air pollution in North Macedonia

- North Macedonia ranked seventeenth internationally in 2021 in terms of annual average $PM_{2.5}$ concentration (μg/m^3), weighted by population according to IQ Air (2021: 11).
- Average annual population weighted $PM_{2.5}$ concentration is estimated to be 37 μg/m^3 in highly polluted areas and 14 μg/m^3 in cleaner, rural areas (World Bank, 2019: 34). The figure for highly polluted areas exceeds WHO guideline amounts (10 μg/m^3) and EU air quality standards (25 μg/m^3).
- Three North Macedonian cities – Skopje, Bitola, and Tetovo – were ranked in 2017 as among the top ten most-polluted in Europe with conditions worsening tangibly and measurably over the past five years (UNEP & WHO, 2019). Other studies suggest that air quality in North Macedonia is improving slowly.
- According to Balkan barometer data, reported by the OECD (2022), in 2019 in response to the question “Do you consider pollution to be a problem in your place of living?”, 45% of respondents in North Macedonia considered it a “very serious problem”.

Causes of air pollution

- When assessing the causes or sources of a particular pollutant, in this instance $PM_{2.5}$, it is important to note that contributions of specific sources may vary by geographical area and that pollution may be more localised in hot spots with some sources being more dominant than others (World Bank, 2019).

- At the national level, the dominant share of $PM_{2.5}$ pollution originates within the geographical boundaries of North Macedonia. The contribution of transboundary sources (about 30%) to ambient air pollution in the country is considerably less than domestic sources (World Bank, 2019).
- The main sources of ambient PM air pollution in North Macedonia in 2014 were identified as; residential heating (36% of total primary emissions), industrial processes (33%) and energy production (20%). Traffic contributed with 2% of the total emissions of PM particles (World Bank, 2019).
- A PM source apportionment study for the City of Skopje conducted in 2015/16 similarly identified sources as originating from household heating (32-36%), traffic (16-19%), road dust 19-20%, and industry (18% of the total PM concentrations) (Dimovska &, Gjorgjev, 2018).
- **Household fuel use**: Household fuel use is consistently identified as the predominant source of PM emissions in North Macedonia. In particular, the use of polluting fuels (e.g., firewood) for heating of households in the winter period causes serious problems with air quality in densely populated residential areas.
- **Energy:** According to the International Energy Agency (IEA), North Macedonia remains reliant on fossil fuels. The majority of its total energy mix, both on supply and demand side, falls under the category of fossil fuels mostly due to the usage of coal and oil.
- **Industry:** In North Macedonia, industrial activities can have a detrimental effect on air quality at the local level due to the prevalence of old industrial plants that lack modern emission reduction systems (MoEPP 2017). According to information provided by the Ministry of Environment and Physical Planning (MoEPP), major sources of pollution include ferroalloy production facilities and power plants.
- **Transport:** Vehicular emissions are a significant source of pollution in many urban areas. The MoEPP (2017) report that at the national level, circa half of the nation's passenger cars and buses are old, belonging to the high-emission vehicle categories. Although transport may not appear to be a significant source of emission at the national level, its impact on air quality and population exposure to $PM_{2.5}$ may be more important at the local level.

Consequences of air pollution

- **Health**: The most extreme estimates suggest that in selected North Macedonian cities 1,903 human lives (excess deaths) are lost annually due to $PM_{2.5}$ exposures (22.3% of total all-cause mortality). The mortality rate attributable to $PM_{2.5}$ exposures (per 100,000 populations) is highest in the city of Tetovo (301); Bitola (234); and Skopje (208) (Dimovska & Gjorgjev, 2018).
- **Economic**: The World Bank (2019) estimated the economic cost associated with mortality from exposure to air pollution in North Macedonia is in the range of US$500–900 million annually, equivalent to 5.2–8.5% of GDP in 2016 (World Bank, 2019: iv-v). This valuation only quantifies economic impacts from premature mortality associated with specific diseases.
- **Political**: Whilst the political consequences of air pollution are multifaceted and can be difficult to identify, it is important to acknowledge the potential impact of poor air quality. For example, North Macedonia's accession to the European Union is dependent on it meeting obligations, including those around air quality.

2. Air pollution in North Macedonia

The Western Balkans is considered to be Europe's most polluted area in terms of a range of air pollutants with levels of air pollution influenced by a complex mix of anthropogenic and meteorological factors. For example, estimates suggest that the region's sixteen power plants produce more air pollution than the 250 power plants of the EU combined. Further to this, during winter months, the region's larger cities report air pollution levels that are the highest in Europe and some of the highest globally (Civil Society Forum, 2021). More broadly, efforts to manage air quality issues (and indeed environmental governance) in the region are challenged by corruption, ineffective law enforcement mechanisms, and the lack of reliable data on the state of the environment (Civil Society Forum, 2021).

More specifically, North Macedonia is considered to have some of the worst air quality in the region, and consequently some of the worst globally (see, for example, Table 1). In particular, air pollution is a significant problem in North Macedonian cities and urban centres (World Bank, 2019). In the context of North Macedonia, exposure to high levels of particulate matter (PM) is a particular concern. PM or atmospheric aerosols is the term used to indicate any solid or liquid particle suspended in the atmosphere. Atmospheric particles vary widely in their physical parameters such as size and chemical composition. PM of small size fractions are considered to be particularly detrimental to public health as they can enter the respiratory system and lead to respiratory disease, asthma, strokes, cancer and heart disease (Thurston et al., 2016). Other health-effects of exposure to PM air pollution include dermal absorption and ocular exposure which may result in eye or skin irritation. The smaller the size of PM particle and the specific nature of its composition, the more impact they are considered to have on health. $PM_{2.5}$ and PM_{10} are particulate matter with aerodynamic diameters less than 2.5 and 10 µm, respectively (Seinfeld & Pandis, 2016). The $PM_{2.5}$ size fraction is the focus of many air pollution studies because it is associated with adverse health outcomes, it is also the focus of this review.

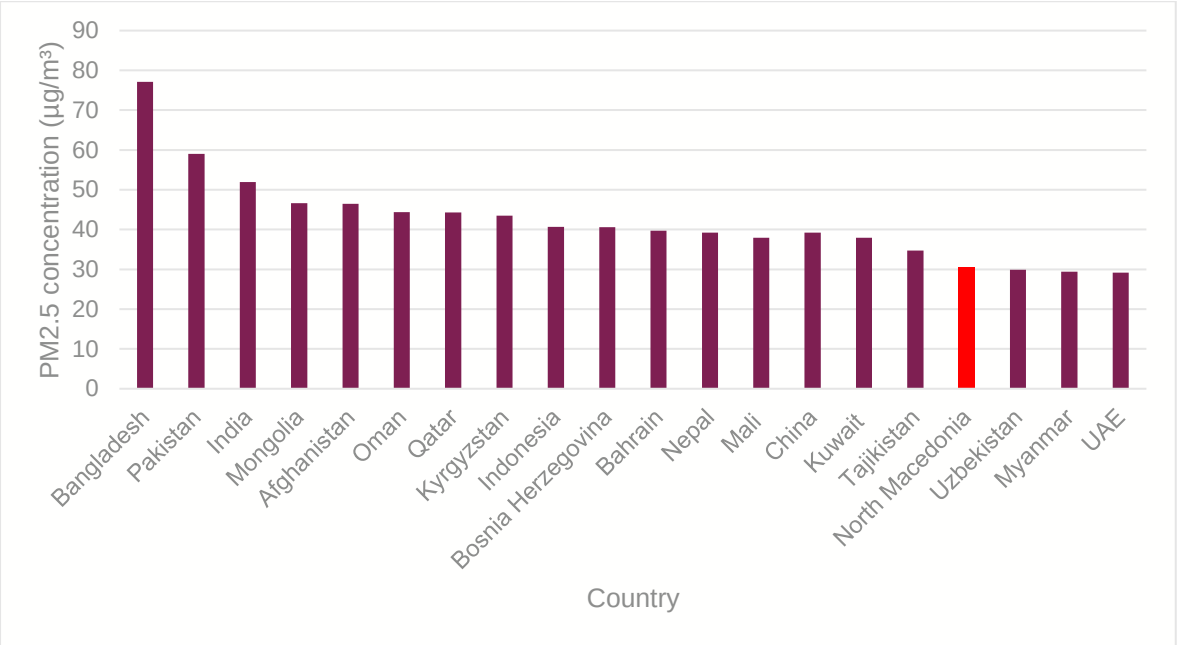
Table 1: ***Air quality limit values in North Macedonia compared to the WHO guidelines and EU standards***

Pollutant		**WHO air quality guidelines**	**EU air quality standards**	**North Macedonia air quality limits**
$PM_{2.5}$ (µg/m³),	Annual Mean	10	25	25
	24-hour mean	25		

Source: ***Author's own collation***

Figure 1 provides an overview of annual average $PM_{2.5}$ concentration (µg/m³), weighted by population in the twenty countries with the worst air quality globally. According to IQ Air (2021: 11), North Macedonia ranked seventeenth internationally for air quality in 2021.

Figure 1: ***2021 World country/region ranking (top 20) arranged by annual average $PM_{2.5}$ concentration (µg/m³), weighted by population based on the available data***



Source: Author's Own created using data from ***IQ Air, 2021: 11*** ***https://www.iqair.com/world-most-polluted-cities/world-air-quality-report-2021-en.pdf***

Exposure to high levels of air pollution is considered to be a major cause of premature death and disease and is the single largest environmental health risk in Europe, causing around 400,000 premature deaths per year (UNDP Website[1]). According to a report produced by the UN Environment Programme (UNEP) and World Health Organisation (WHO), three North Macedonian cities – Skopje, Bitola, and Tetovo – were ranked in 2017 as among the top ten most-polluted in Europe with conditions worsening tangibly and measurably over the past five years (UNEP & WHO, 2019). In North Macedonia, average annual population weighted $PM_{2.5}$ concentration is estimated to be 37 µg/m^3 in highly polluted areas and 14 µg/m^3 in cleaner, rural areas (World Bank, 2019: 34).

Antilla et al. (2016: 134) reported that $PM_{2.5}$ concentration levels are particular high in the nation's capital, Skopje. Annual means for $PM_{2.5}$ were 56 µg/m^3 at Centar and 55 µg/m^3 at Karpos monitoring stations in Skopje. Antilla et al.(2016) highlighted that the extremely high concentrations in early winter are the main reason that air pollutant concentrations did not comply with European air quality standards in Skopje during their study period.

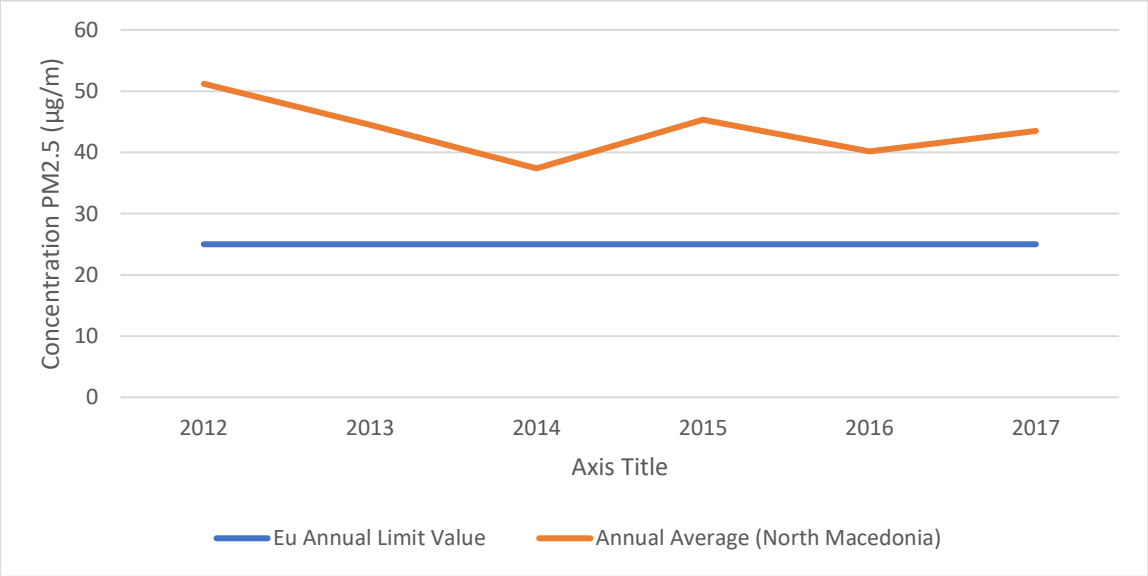
Continuous monitoring in selected North Macedonian cities found $PM_{2.5}$ hourly concentrations of up to 800 µg/m^3, more than 30 times higher than the 24-hour mean set by the WHO guidelines (at 25 µg/m^3) to protect human health (Anttila et al. 2016). In 2016, annual average $PM_{2.5}$ concentration in Tetovo reached six times the WHO health-based guidelines. In the capital city Skopje, annual average concentrations of ambient $PM_{2.5}$ were four times higher than the WHO air quality guideline values (World Bank, 2019: 18). Air pollution has thus reached levels

[1] https://innovation.eurasia.undp.org/project/if-we-were-counting/

considered health threatening in most urban locations across North Macedonia, particularly during winter months (FMI & MoEPP, 2017).

Various commentators have reflected that PM concentrations have remained at a broadly similar level during periods of analysis, exceeding limit values significantly in urban locations (see Figure 2). These high PM concentrations are considered to pose a serious risk to the health of the population.

Figure 2: ***Trend in annual mean concentration across all stations (North Macedonia) against the EU standard $PM_{2.5}$ ($\mu g/m^3$ for the years 2012-2017)***



Source: ***EEA, 2021 reproduced under*** **CC BY 2.5 DK**

More recent studies have reported that North Macedonia's annual exposure to $PM_{2.5}$ air pollution decreased from 39.1 $\mu g/m^3$ in 2005 to 33 $\mu g/m^3$ in 2017 (OECD, 2022). Despite this decline, it remains the highest level in the Western Balkans (average for the West Balkans 25.77 $\mu g/m^3$), more than double the EU and OECD averages (13.1 $\mu g/m^3$ and 12.5 $\mu g/m^3$, respectively) and far above the WHO recommended maximum (annually) of 10 $\mu g/m^3$.

In terms of public perception, air pollution issues have assumed increased prominence as a social and political issue in recent years. According to Balkan barometer data in 2019, reported in OECD (2022), in response to the question "Do you consider pollution to be a problem in your place of living?", respondents in North Macedonia reported the following:

- Very serious problem 45%
- Somewhat serious problem 37%
- Not too serious problem 11%
- Not a problem at all 5%
- I don't know/I refuse to answer 2%

$PM_{2.5}$ emissions are not expected to decline markedly under existing policies due to the combustion of fuelwood in household stoves and boilers with current energy projections do not foresee major shifts away from fuelwood burning in households (World Bank, 2019).

To make effective emission reduction measures, not only the pollution levels but also the relationship between emissions, atmospheric conditions and local source contributions needs to be understood. In North Macedonia there is an expanding, though limited, systematic and reliable data on air pollutant emissions as well as their formation and concentrations (Antilla et al., 2016).

3. Causes of air pollution

Key sources

Whilst the causes or sources of poor air quality can be identified, these causes and underlying processes may vary within and between cities (MoEPP, 2017). Natural sources of PM include dust storms, ocean/sea spray (sea salt), dust erosion due to wind, forest fires, volcanic eruptions, and the release of biogenic PM (e.g., pollen and spores). Man-made sources include traffic, non-combustion and combustion industrial processes, power plants, construction activities, agricultural activities (including agricultural waste burning) (Haq & Schwela, 2008: 6). A key contributor to heightened levels of PM in urban settings is the combustion of solid and liquid fuels for power generation, domestic heating, cooking or lighting and in vehicle engines. PM can also be formed in the atmosphere through chemical processing of its gaseous precursors.

Source Apportionment is an approach used for the identification of ambient air pollution sources and the quantification of their contribution to pollution levels. This task can be accomplished using different methods: emission inventories, source-oriented models and receptor-oriented models. A number of source apportionment studies have been undertaken in North Macedonia, at both national and local levels.

At the national level, the dominant share of $PM_{2.5}$ pollution originates within the geographical boundaries of North Macedonia. The contribution of transboundary sources (about 30%) to ambient air pollution in the country is considerably less than domestic sources (World Bank, 2019).

The main sources of ambient PM air pollution in North Macedonia in 2014 were identified as: residential heating (36% of total primary emissions), industrial processes (33%) and energy production (20%). Traffic contributed 2% of the total emissions of PM particles (World Bank, 2019).

A PM source apportionment study for the City of Skopje conducted in 2015/16 identified similar sources originating from household heating (32-36%), traffic (16-19%), road dust (19-20%), and industry (18% of the total particulate matter concentrations) (Dimovska & Gjorjev, 2018).

According to a 2017 report from North Macedonia's MoEPP, the main emission sources for $PM_{2.5}$ in 2016 in North Macedonia were residential heating with a share of 58%, industrial processes and product use (mainly ferroalloys production) with 20%, and energy industries with 6% (see Figure 3). Fugitive emissions, agriculture, and waste are reported to be minor sources of $PM_{2.5}$ emissions in 2016 (World Bank, 2019: 40).

Figure 3: ***Contribution of different emission source sectors to $PM_{2.5}$ concentrations in Karpos urban background station in Skopje.***

This image has been removed for copyright reasons. The image can be viewed at ***https://air.moepp.gov.mk/wp-content/uploads/2017/07/AirQualityReport_EN.pdf***

Source: MoEPP, 2017: 26

When assessing the causes or sources of a particular pollutant, in this instance $PM_{2.5}$, it is important to note that contributions of specific sources may vary by geographical area and that pollution may be more localised in hot spots with some sources being more dominant than others (World Bank, 2019).

Household fuel use

Household fuel use is consistently identified as the predominant source of PM emissions in North Macedonia. Source apportionment analysis conducted by the World Bank (2019) indicates that at the national level, the residential sector is the largest source of exposure to harmful $PM_{2.5}$ associated with the burning of solid fuels in homes (World Bank, 2019). Household fuel use is a socially sensitive issue with household income often determining fuel types utilised[2] (World Bank, 2019).

In particular, the use of polluting fuels for heating of households in the winter period causes serious problems with air quality in densely populated residential areas since many households and administrative entities in the country still use fuelwood as a primary source of heating (World Bank, 2019). The primary energy supply profile for North Macedonia indicates that coal and peat accounted for about 50% of primary energy supply in 2012, followed by oil products and biomass and waste accounting for about 20% each respectively (World Bank, 2019: 41).

In a similar vein, MoEPP (2017) highlight that inefficient small-scale combustion in residential fire places and boilers, together with the use of poor-quality fuels like moist or treated wood or even waste materials, cause problems especially in densely populated residential areas. Limited and dilapidated district heating systems and the high price of electricity further increase the use of solid fuels for residential heating (MoEPP, 2017).

In small stoves, fireplaces and heating boilers the combustion conditions may be inadequate (e.g., low temperature and low combustion air supply) and the quality of the fuel used may be poor (e.g., moist wood) or even unacceptable (e.g., waste). In addition, the emissions are released directly into the household. According to the 2015 official census there were 559,187 dwellings in the country. According to the survey conducted in 2015 and of the total number of households, 62% consume fuel wood as the primary source of heat, 29% use electricity, 8% rely on heat energy from district heating systems, and the remaining 1% utilise other types of heating sources (see Figure 4) (State Statistical Office, 2015: 24)

[2] Europe's energy price crisis will likely influence household fuel use in North Macedonia.

Figure 4: ***Share of the number of households in the total number of households by primary energy commodity used for heating.***

This image has been removed for copyright reasons. The full image can be viewed at ***https://www.stat.gov.mk/Publikacii/6.4.15.03.pdf***

Source: ***State Statistical Office, 2015: 24***

$PM_{2.5}$ emissions are not expected to decline markedly under existing policies due to the combustion of fuelwood in household stoves and boilers and as current energy projections do not foresee major shifts away from fuelwood burning in households (World Bank, 2019). Policy options for supporting transitions in household fuel use identified by the World Bank include; programmes to substitute traditional stoves with more efficient ones, medium- to long-term options may include expanding district heating and targeted subsidies for project beneficiaries who cannot afford to pay the full costs of substituting their stoves with cleaner alternatives. The World Bank (2019) also stresses the need for public awareness campaigns to support stove replacement programmes to facilitate adoption of cleaner stoves by households.

Energy

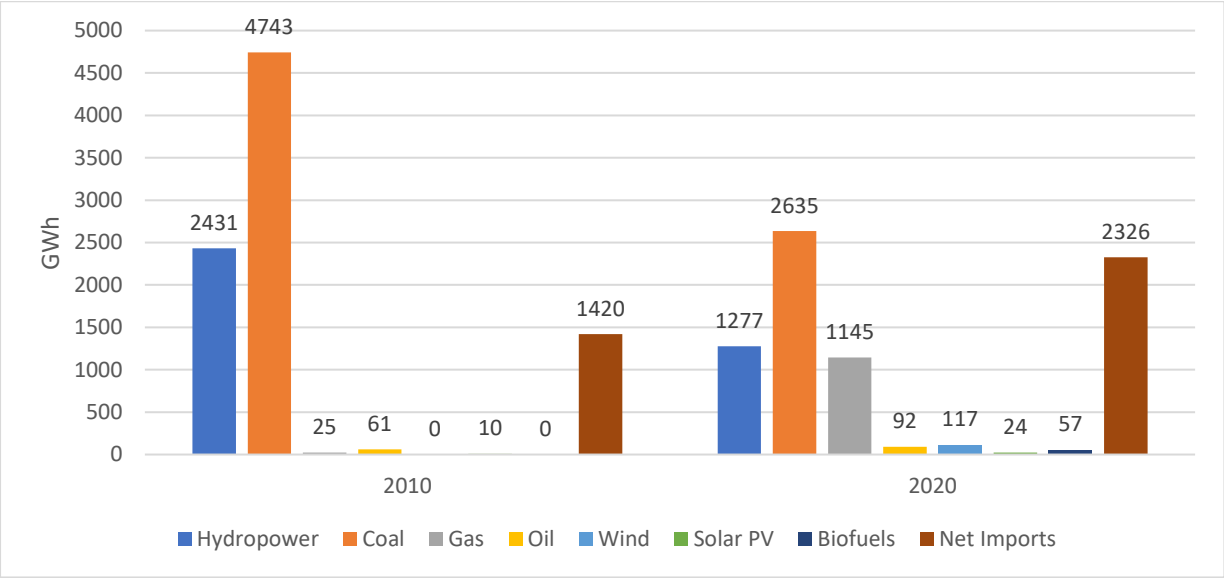
According to the International Energy Agency (IEA), North Macedonia remains reliant on fossil fuels. The majority of its total energy mix, both on supply and demand side, falls under the category of fossil fuels mostly due to the usage of coal and oil. In recent years, efforts have been made to include more natural gas in the energy mix, facilitated by the development of new infrastructure and connecting pipelines as of 2020 (Vidoeski, 2021: 10).

Further to this reliance on fossil fuels, energy production and distribution systems are often aged, inefficient, unreliable and polluting. Domestic electricity production relies mostly on poor-quality lignite in old thermal power plants. Combined heat and power generation as well as wind and hydro power generation are still rare (though expanding) in the country (MoEPP, 2017). Electricity generation is dominated by coal (58%) and hydro power (33%) (EBRD, 2019: 17).

Problems with electricity supply reflect broader difficulties in developing a more sustainable energy mix and improving resource efficiency (EBRD, 2019). Most electricity is generated in outdated thermal power plants with an efficiency of 32%, fuelled by low-quality coal (EBRD, 2019: 17). The country ranks among the most energy-intensive economies in the region due to the high share of coal and oil in primary energy production.

Due to old electricity transmission and distribution networks, secure, reliable and constant electricity supply remains an issue in North Macedonia. It is reported that one-quarter of firms considered electricity a major constraint in 2019, along with political instability, practices of the informal sector and access to finance (OECD, 2022). Recent improvements electric power distribution losses saw figures lost decrease from 15.5% in 2014 to 13.4% in 2022, and electric power transmission losses are in line with EU levels (1.8% in 2019) (OECD, 2022). The North Macedonian energy mix is also changing with more an increasing range of sources and less dependency on coal (see figure 5).

Figure 5: ***North Macedonia electricity mix 2010 and 2020***



Source: ***IEA Statistics*** reproduced under **CC BY-SA 4.0**

Some 50% of the domestic electricity production comes from coal (lignite), 33% from hydropower, 13.4% from gas and around 3% from wind, biomass and solar together. Electricity from coal is generated in two thermal power plants built in the 1980s, REK Bitola and REK Oslomej, managed by the state-owned company *Elektrani na Severna Makedonija*, with a total installed capacity of around 800 MW. Construction of a new thermal power plant (Mariovo), with 300 MW power, appears in the government's main long-term strategic energy documents but has not been included in the new strategy adopted in December 2019 (OECD, 2022).

Industry

In North Macedonia, industrial activities impact on air quality at the local level due to the prevalence of old industrial plants that lack modern emission reduction systems (MoEPP 2017). According to information provided by the MoEPP, major sources of pollution include ferroalloy production facilities and power plants. Other sources include facilities for cement, iron and steel production, and refineries. The World Bank (2019) note that as of 2018/19, some industrial facilities were out of operation, and others experienced temporary stops in operation due to financial problems. For example, the Jugohrom ferroalloy production facility has not been operational since 2016 (World Bank, 2019).

Major installations which have historically has a significant contribution to the national emissions are (MoEPP, 2017: 16-17):

- Power plants generating electricity using lignite and heavy fuel oil such as REK Bitola and REK Oslomej;
- Industrial sector producing ferroalloys (installation Jugohrom Alzar DOOEL);
- Other facilities including cement production installation Titan in Skopje, iron and steel production installations Makstil AD Skopje and Arcelor Mittal and Feni Industries for manufacturing of ferro-nickel.

Transport

Vehicular emissions are a significant source of pollution in many urban areas. The MoEPP (2017) report that at the national level, circa half of the nation's passenger cars and buses are old, belonging to high-emission vehicle categories (i.e., Euro 0-2[3]). In North Macedonia, air pollution from road traffic is related to factors such as high intensity of traffic and the age of vehicles and poor maintenance. Congested traffic flows and poorly developed or totally absent public transport worsen the situation (MoEPP, 2017). Whilst vehicle inspection is mandated, these inspections have not reduced vehicle emissions, especially those associated with aging and growing fleets.

Figure 6: ***Share of the registered passenger cars, heavy duty (HDV) and light duty (LDV) vehicles and buses belonging to the various Euro emission classes in 2015***

This image has been removed for copyright reasons. The full image can be viewed here: ***https://www.stat.gov.mk/Publikacii/6.4.15.03.pdf***

Source: MoEPP, 2017: 16

Although transport may not appear to be a significant source of emissions at the national level, its impact on air quality and population exposure to $PM_{2.5}$ may be more important at the local level and there exists a need to better understand the contribution of this sector (MoEPP, 2017).

Agriculture

Agriculture is a minor source of PM emissions. Most farms in the country are small individual holdings. Cattle and dairy farms are more significant sources of emissions (particularly ammonia). There may also be a small impact from the burning of waste including agricultural waste (World Bank, 2019).

Solid waste management

Waste production in North Macedonia is relatively low, but its collection is not always effective. On average, the waste production rate amounts to 301kg of waste per capita per year, lower than the EU and OECD averages of 492kg and 525kg, respectively, and lower than the rest of the region. The collection rate ranged between 73.98% in 2011 and 80.81% in 2017 (State Statistical Office, 2018: 116 cited in OECD, 2022); however, populations living in rural areas are not always adequately served.

Large scale-controlled waste incineration is rare in the country, as there is only one clinical waste incinerator operating. Instead, more than 99% of the municipal solid waste is landfilled, mostly in landfills which do not fulfil European standards (with exception of Drisla landfill located in Skopje). Whilst the waste sector is not a major source of air pollutants, MoEPP, (2017) note that

[3] The European emission standards are vehicle emission standards for pollution from the use of new land surface vehicles sold in the European Union and EEA member states and the UK, and ships in EU waters. The standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards i.e., the lower the number the more emitting the vehicle is.

the absence of proper waste management and recycling systems increase the amount of uncontrolled waste combustion such as open burning of household waste (OECD, 2022). Also, agricultural biomass burning may cause local air quality issues.

Transboundary air pollution

According to the European Commission (2020: 31), transboundary (i.e., international) pollution is a significant source of $PM_{2.5}$ in the cities of the West Balkans (40% of total) followed by the city and commuting area's own emissions (19%) and the national emissions (16%). In addition, there is a considerable variation between the cities in the share of sources emitted at the local level, suggesting there is no single set of measures appropriate for all of them. (EC, 2020: 31).

In North Macedonia, the dominant share of $PM_{2.5}$ pollution originates within the nation's geographical boundaries. The contribution of transboundary sources (about 30%) to ambient air pollution in the country is considerably less than domestic sources (World Bank, 2019)[4].

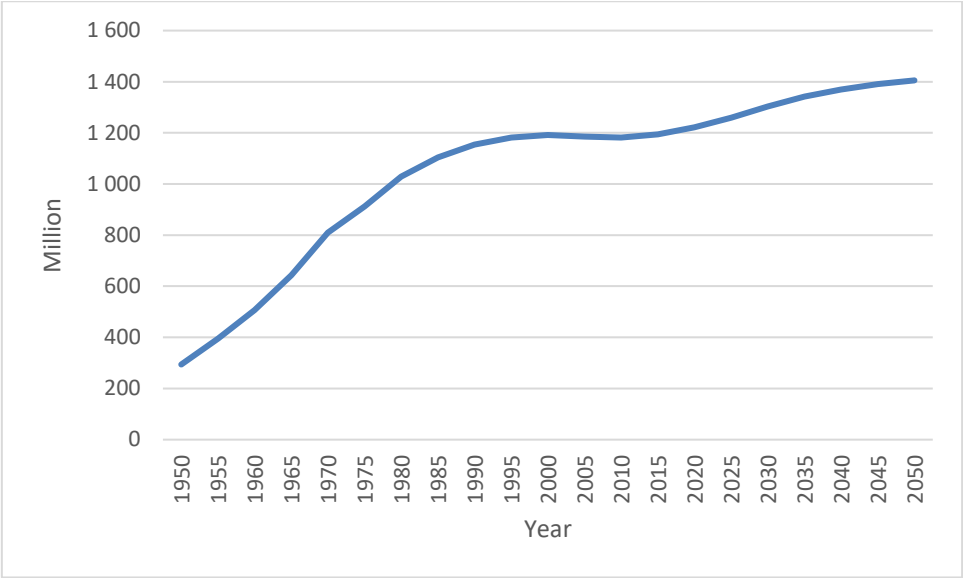
Factors that influence levels of air pollution

Urbanisation

Air pollution is a complex issue with many factors contributing to increased concentrations of the main pollutants (e.g., urbanisation rates, topography, emissions sources, environmental factors and meteorology) (Spiridonov et al., 2021). According to World Bank data[5], in 2020, 59% of the population lived in areas designated as urban i.e., over 1,200,000 people.

Figure 6: ***North Macedonia's urban population (in millions) 1950-2050***

[4] For a detailed discussion of transboundary air pollution see Klein, H. et al. (2021). Transboundary air pollution by sulphur, nitrogen, ozone and particulate matter in 2019 North Macedonia. Norwegian Meteorological Institute. https://emep.int/publ/reports/2021/Country_Reports/report_MK.pdf



Source: Author's own using data from UNDESA, World Urbanisation Prospects, 2018

In North Macedonia, urban air quality is consistently identified as an issue of concern. The development of densely built urban areas, including the reduction of green areas in cities, has been identified as having an impact on the formation of pollution (MoEPP, 2017). Emissions from construction and demolition activities have also been identified as locations where PM air pollution can be an issue, especially in rapidly urbanising cities. According to MoEPP (2017) this source has a minor contribution to national emissions but can have an impact on local air quality (MoEPP, 2017).

In the 20th century Skopje has experienced rapid urbanisation, growth of industrial activities, and reconstruction after the 1963 earthquake. With a comparatively large number of industrial point sources and higher traffic flows than other cities in the country, the Skopje agglomeration has historically experienced frequent episodes of heavy pollution. During dry periods, the combination of mineral dust and emissions from residential heating, the transport sector, and industrial activities within the city increase the concentrations of inhalable particles (Martinez et al., 2018).

Topographical and Meteorological factors

Meteorological parameters such as temperature, wind speed, and precipitation have a significant impact on air pollution concentrations measured in ambient air. This effect is mainly due to

- influencing atmospheric dispersion of pollutants via stability of the atmosphere and
- wash-out of pollutants in the atmosphere via precipitation.

Furthermore, atmospheric stability is influenced by temperature, wind speed, and inversion, etc. Unstable atmospheric conditions create enhanced dispersion conditions, hence lower concentrations of air pollutants, whereas stable atmospheric conditions result in stagnant air, hence higher concentrations of air pollutants (Antilla et al., 2016).

North Macedonia's unique geographic location has a particular impact on air quality. Mountains generally reduce the flows of air in valleys and allow pollutant levels to increase at ground level. In North Macedonia, the atmosphere tends to be stable (lower wind speeds) during night and neutral to unstable during days (higher wind speeds). This explains, in part, why air pollution concentrations increase during the night even though the emissions are typically lower during this time (Antilla et al., 2016). In cities surrounded by mountain ranges the most severe pollution episodes are created during specific atmospheric conditions, so called temperature inversions (World Bank,2019). These inversions occur during the winter months when normal atmospheric conditions (cool air above, warm air below) become inverted and the normal vertical mixing of warm and cold air is prevented. Inversions trap a layer of cold air under a layer of warm air. The warm layer acts much like a lid, trapping pollutants in the cold air near the valley floor. Pollutants do not disperse or dilute but remain trapped at the ground level (Antilla et al., 2016).

Monthly average PM concentrations in North Macedonia show a distinct pattern with higher ambient concentrations during winter months (especially November, December, January, and February) and lower ambient concentrations during summer months (Antilla et al., 2016). This is related to increased atmospheric dispersion of air pollutants during summer months and poor atmospheric dispersion of air pollutants in winter months due to meteorological parameters (World Bank, 2019: 27).

The high winter time PM concentrations are thus related to higher direct emissions (residential heating with wood in particular) but also meteorological conditions that limit the dispersion of emissions and facilitate chemical reactions that create more secondary particles from e.g., vehicle exhausts. Winter time smog episodes are typical in cities which are located in valleys (MoEPP, 2017: 22).

Antilla et al. (2016) analysed air quality in Skopje over a twelve-month period and reached the following conclusions. In Skopje, high levels of air pollution recorded during winter months are related to persistent multi-day stable atmospheric conditions, during which emitted pollutants accumulate in the valley. Their study highlighted that during particularly poor air quality episodes, 24-hour mean for $PM_{2.5}$ was reported at 230 $\mu g/m^3$, with highest hourly $PM_{2.5}$ concentrations of 500 $\mu g/m^3$ (December 2011). During this winter episode, clear sky conditions, light winds and low nocturnal temperatures were recorded. Under these circumstances, the mountains surrounding the city of Skopje city trapped the pollution inside the valley (Antilla, et al. 2016: 140)

Legislation and enforcement

The Government of North Macedonia has made significant efforts to develop a comprehensive legal framework for ambient air quality management that is harmonised with European legislation (World Bank, 2019). Achieving sustained reductions in air pollution, however, requires further government commitment, dedicating significantly higher resources, and building capacity at different levels to both monitor air quality and to enforce that legislation that exists. In particular, World Bank (2019) highlight that agencies responsible for air quality management tasks need to be adequately staffed with people having the requisite technical skills and adequate budgets allocated not only for sustained operation and maintenance of the air quality monitoring network but other critical aspects including data analysis, reporting and management, chemical analyses, atmospheric modelling, and health impact assessment (World Bank, 2019).

Strengthening institutional capacity to enforce existing air pollution limits is another pressing priority. As of 2015, a total of nineteen inspectors were responsible for enforcing all environmental laws at the national level. Resource constraints are also evident at the municipal level, leading to individuals being responsible for inspections, issuance of permits, and other documentation. Sustained, higher resource allocation for enforcement and strong political will are key to improve enforcement of existing air quality laws and regulations (World Bank, 2019).

Informal economy

According to estimates from the Statistical Office of North Macedonia, the informal or “grey” economy accounts for about 20% of GDP, other estimates suggest it is significantly larger – between 24 and 47% according to one survey of different studies and methods used to estimate the share (EBRD, 2019: 9). As identified by the European Bank for Reconstruction and Development (EBRD, 2019) the large informal economy places an unfair burden on legitimate businesses, with weak levels of governance and enforcement of regulations. This may have an impact on local air quality if emissions regulations are not enforced.

COVID-19

The impact of the COVID-19 pandemic on air pollution was multifaceted. Studies in North Macedonia have highlighted a decrease in the levels of all pollutants measured during the COVID-19 period in 2020 compared to those reported between 2017 and 2019 (Dimovska & Gjorgjev, 2020: 355).

The first movement restrictions in the country were introduced in March 2020, followed by stricter movement restrictions in April 2020. Dimovska and Gjorgjev (2020: 357) identified a substantial decrease in PM concentrations in all cities observed in the study (15–48% for $PM_{2.5}$ during the strictest COVID restrictions). They assert that this was likely attributable to the significant reduction of vehicular traffic and transport, and to the reduction or complete stop of industrial activities given restrictions imposed by the authorities (Dimovska & Gjorgjev, 2020: 357).

4. Consequences of air pollution

A significant proportion of Europe's urban population lives in cities where EU air quality standards for the protection of human health are regularly exceeded, with North Macedonian cities ranking as some of the worst for air quality. Air pollution continues to have significant impacts on the health of Europeans, particularly in urban areas. These health impacts have economic costs, cutting short lives, increasing medical costs and reducing productivity through lost working days. The pollutants with the most serious impacts on human health are PM, nitrogen dioxide and ground-level ozone (EBRD, 2019). Alongside these health costs, air quality exerts a significant economic impact (associated with health-related costs) and is an issue of political concern. Whilst various estimates exist, the EBRD estimate that approximately 1,350 lives are lost annually due exposure to PM, costing the North Macedonian economy EUR 253 million, or 3.2% of GDP (EBRD, 2019: 17).

Health

It is well documented that the strongest and most rigorously proven causal associations between poor air health and poor air quality are between cardiovascular and pulmonary disease and $PM_{2.5}$ pollution. Particles of smaller size reach deeper into the lower respiratory tract and thus have greater potential for causing lung and heart diseases. As a Lancet review (Landrigan et al., 2017) reports, $PM_{2.5}$ air pollution is associated with several risk factors for cardiovascular disease, including hypertension, increased serum lipid concentrations, accelerated progression of atherosclerosis, increased prevalence of cardiac arrhythmias, increased numbers of visits to emergency departments for cardiac conditions, increased risk of acute myocardial infarction, and increased mortality from cardiovascular disease and stroke. Recent work by Burnett et al. (2018) suggests that health impacts of $PM_{2.5}$ are more significant than previously understood and that exposure to $PM_{2.5}$ contributes to mortality from causes other than typically examined in global burden of disease studies.

Despite the documented high levels of pollution in North Macedonia, the published evidence on its health impacts is limited (Martinez et al., 2018). According to Institute for Health Metrics and Evaluation (IHME) data for North Macedonia, in 2019 the risk factors listed as driving the most death and disability combined were listed as follows. Air pollution ranked 6th and was the leading environmental/occupational risk (IHME Data[6]):

1. High Blood Pressure (metabolic risk)
2. Tobacco (Behavioural risk)
3. High Fasting Plasma Glucose (metabolic risk)
4. High Body-Mass Index (metabolic risk)
5. Dietary Risks (Behavioural risk)
6. Air Pollution (Environmental/occupational risk)
7. High LDL (metabolic risk)
8. Kidney Dysfunction (metabolic risk)
9. Alcohol Use (Behavioural risk)
10. Non-Optimal Temperature (Environmental/occupational risk)

A World Bank study (2012 cited in World Bank, 2019) confirmed that air pollution in North Macedonia was one of the highest in Europe and that exposure to $PM_{2.5}$ was responsible for more than 1,350 deaths. Martinez et al. (2018) estimated that in 2012, long-term exposure to $PM_{2.5}$ (49.2 µg/m^3) caused 821 to 1,519 premature deaths. The social cost of the predicted premature mortality was estimated at between 570 and 1470 million euros. Moreover, $PM_{2.5}$ was also estimated to be responsible for between 104–977 hospital admissions from cardiovascular diseases, and between 937–1869 admissions for respiratory disease in 2012 (Martinez et al., 2018). Regarding spatial representation, 45% of the burden of diseases (the overall health impact and health outcomes of exposure) were in Skopje in the period 2012-2016 (Dimovska & Gjorgjev, 2018).

[6] https://www.healthdata.org/macedonia

More recent research estimates that about 1,600 people die prematurely every year as a result of exposure to $PM_{2.5}$ in North Macedonia with about 21% of this burden carried by the capital city, Skopje (World Bank, 2019: iv). The total health burden is about twice as high as the burden in neighbouring Kosovo. In terms of leading causes of death, the World Bank (2019: iv) estimate that 80% of the total number of ambient air pollution related deaths are from cardiovascular diseases, of which about 95% occur in age groups 50 years and above. The number of deaths from lung cancer is highest in age group 50–69 years. Cardiovascular deaths mostly affect populations older than 65 years, suggesting that mitigation measures to reduce the adverse health impacts attributed to air pollution in North Macedonia should include a focus on this subgroup of the population (World Bank, 2019: iv).

The most extreme estimates suggest that In selected cities 1,903 human lives (excess deaths) are lost annually due to $PM_{2.5}$ exposures (22.3% of total all-cause mortality). The mortality rate attributable to $PM_{2.5}$ exposures (per 100,000 populations) is highest in the city of Tetovo at 301; Bitola at 234; and Skopje at 208 (Dimovska and Gjorgjev, 2018: 7527). Dimovska and Gjorgjev (2018: 7527) conclude that if the limit values of the $PM_{2.5}$ complied with the existing EU and WHO limit values, 908 to 1,547 lives could be saved.

Table 2: ***Five-year all-cause mortality and deaths attributable to PM2.5 air pollution.***

City	**All-cause mortality**			**PM2.5 attributable deaths**		
	Males	Females	Total	#	95% confidence interval	(%)
Skopje	2,505	2,341	4,846	1,052	736.0-1379.1	21.70
Bitola	576	575	1,151	223	155.6-294.2	19.40
Veles	316	290	606	109	75.7-143.9	18.00
Kavadarci	215	195	410	85	59.6-112.0	20.70
Kicevo	238	234	472	113	79.5-147.6	23.90
Kocani	198	179	377	60	41.8-80.2	15.90
Tetovo	351	321	672	260	188.7-328.2	38.70
Total	4,399	4,135	8,534	1,902	1,296-2,429	22.30

Source: Dimovska & Gjorgiev, 2018: 7527 reproduced under CC BY 4.0

It should be noted that obtained results for the number of extra deaths in all studies are influenced by other factors, such as the age distribution of the population (those at older ages are at higher risks), the presence of larger groups of vulnerable populations or populations with a lower level of education and lifestyle factors, such as smoking, time spent outdoors etc. (Dimovska & Gjorgiev, 2018: 7529). Population age groups over 50 years carry a significant share of the health burden, at about 94% (World Bank, 2019:I v).

To better understand health impacts of ambient air pollution on its population, North Macedonia needs to strengthen capacity for conducting health impact assessments and improve statistics on disease-specific mortality attributable to ambient air pollution and availability of morbidity data attributable to ambient air pollution for specific diseases, age groups, and locations (World Bank, 2019).

Economic

Alongside health impacts, air pollution also exerts an economic impact. PM frequently exceeds daily and annual limit values and influences day-to-day health and ability to work. Converting lost years of life and disabilities into Disability Adjusted Life Years (DALYs), these health effects in North Macedonia represent an annual economic cost of approximately €253 million or 3.2% of GDP (Meisner et al., 2015). Premature death accounts for over 90% of the total health burden since this represents a loss of total life-long income. A reduction of 1μg/m^3 in ambient PM_{10} or $PM_{2.5}$ would imply 195 fewer deaths and represent an economic savings of €34 million per year in reduced health costs (Meisner et al., 2015).

More recently, the World Bank (2019) estimated the economic cost associated with mortality from exposure to air pollution in North Macedonia in the range of US$500–900 million annually, equivalent to 5.2–8.5% of GDP in 2016 (World Bank, 2019: iv-v). This valuation only quantifies economic impacts from premature mortality associated with specific diseases. Other kinds of health impacts with associated costs, such as hospital stays, cost of illness, and lost workdays, are not valued in this report. Therefore, the cost to society and percentage of GDP is higher. Of the average value of US$750 million, the cost of pollution in urban and industrial areas is estimated at US$600 million, while an estimated US$150 million comes from other areas. (World Bank, 2019: iv-v).

Political

Whilst the political consequences of air pollution are multifaceted and can be difficult to identify, it is important to acknowledge the potential impact of poor air quality on this sphere.

Accession to the European Union: North Macedonia's accession to the European Union (EU) is governed by Article 49 of the Treaty on EU which stipulates that a state that wishes to apply for membership must satisfy a number of conditions – including adapting national institutions, standards and infrastructure to meet its obligations such as those around air quality. North Macedonia's application to join the EU was approved in 2020 and the country is implementing EU laws and standards.

The adoption, implementation and enforcement of Chapter 27 of the EU acquis on Environment is an obligation for countries joining the European Union in the framework the "Stabilisation and association process". Reducing the emissions of air pollutants and greenhouse gases (GHG) is a

priority which is interlinked with energy, transport and health policies, among others (EC, 2020). A continuing commitment is needed to achieve full alignment with EU environment acquis.

Domestic politics: Air pollution has been seen to be a source of tension in domestic politics in a number of countries. Indeed, those locations with poor air quality have seen increased demands for action. In North Macedonia, polling undertaken by Balkan barometer have illustrated that air pollution is considered a Very serious problem by 45% of respondents and a Somewhat serious problem by 37% (Balkan barometer cited in OECD, 2022). The extent to which this translates into demands for political action requires further analysis.

Further to the above, in instances where different political parties hold power at national, subnational and municipal levels, allocation of responsibilities and resources for air quality management can be a source of tension. Whilst analysis of the relationship between different levels of government and their management of air quality in North Macedonia is limited, the allocation of resources and indeed apportionment of blame for high levels of air pollution may become a source of tension.

Transboundary air pollution: As illustrated by the EC (2020: 31), transboundary (i.e., international) pollution is, a significant source of $PM_{2.5}$ in the cities of the West Balkans (estimated to be up to 40%). As countries implement efforts to improve air quality at the national level, tensions may arise between countries if sources of pollution (i.e., factories or industries) located in other countries are seen to have a detrimental impact on national air quality. As noted by the EC (2022), improving the air quality in the countries of the West Balkans would also contribute to reducing levels of pollutants in the EU neighbouring countries (EC, 2022).

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