Report No: AUS0001228

Western Balkans

Regional AQM - Western Balkans

Report – AQM in North Macedonia

October 2019

ENV

Document of the World Bank

AIR POLLUTION MANAGEMENT IN NORTH MACEDONIA

October 2019

Acknowledgments

This analytical work was conducted by a team led by Yewande Awe (Task Team Leader) and comprised Maja Murisic (GENLC), Gulana Hajiyeva (GENEC), Nina Rinnerberger (GENEC), Dorothee Chen (GHN03), Michael Brody (GENE2), Elena Strukova (GENEC), Oznur Oguz Kuntasal (IFC), Santiago Enriquez (GENDR), and Paula Posas (GENGE). The extended team included Markus Amann, Jens Borken, Chris Heyes, Janusz Cofala, Gregor Kiesewetter, and Zbigniew Klimont (International Institute for Applied Systems Analysis). The peer reviewers at the concept stage of the study were Helena Naber, Craig Meisner, and Ernesto Sanchez-Triana. The report benefited from valuable comments by peer reviewers Helena Naber, Craig Meisner, and Gabriela Azuela Elizondo.

The team expresses gratitude to the Government of the Republic of North Macedonia and several stakeholders who collaborated with the team, including the Ministry of Environment and Physical Planning, Ministry of Economy, National Hydrometeorological Service, Ministry of Health (Institute of Public Health), and the Delegation of the European Union to the Republic of North Macedonia. The following persons from the Macedonian Environmental Information Center (MEIC) contributed to the preparation of this report: Ms. Svetlana Gjorgjeva (Head of Department), Ms. Aneta Stefanovska (Head of Air Quality Monitoring Unit), Mr. Aleksandra N. Krsteska (Adviser), Mr. Nikola Golubov (Adviser), and Ms. Martina Spasovska (Adviser). In addition, Professor Dragan Gjorgjev and Dr. Mirjana Dimovska, from the Institute of Public Health, contributed to the preparation of this report.

The team acknowledges Mr. Jani Makraduli, Deputy Minister, Ministry of Environment and Physical Planning, and Ms. Ana Petrovska, State Secretary, Ministry of Environmental and Physical Planning, for their support of this study.

The team thanks the World Bank Country Management team including Linda Van Gelder, Marco Mantovanelli, and Simon Ellis for their guidance and support. The team is also grateful to the Environment Global Practice Management team including Kseniya Lvovsky, Ruxandra Floroiu, Laura Tuck, Karin Kemper, and Benoit Bosquet for their guidance and support. Grace Aguilar, Linh Nguyen, Luan Aliu, and Anita Bozinovska are gratefully acknowledged for their administrative support.

Abbreviations and Acronyms

AAP	Ambient Air Pollution
AMHIB	Air Monitoring and Health Impact Baseline
AQM	Air Quality Management
BC	Black Carbon
BCA	Benefit-cost Analysis
CEA	Country Environmental Analysis
CEM	Continuous Emissions Monitoring
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
EMEP	European Monitoring and Evaluation Program
EPB	Environmental Protection Bureau
EU	European Union
GAINS	Greenhouse Gas-Air Pollution Interactions and Synergies
GBD	Global Burden of Disease
IHD	Ischemic Heart Disease
IHME	Institute for Health Metrics and Evaluation
IPPC	Integrated Pollution Prevention and Control
LAAQ	Law on Ambient Air Quality
LRI	Lower Respiratory Illness
LSGU	Local Self-Government Unit
MEIC	Macedonian Environmental Information Center
MEPP	Ministry of Environment and Physical Planning
MTFR	Maximum Technically Feasible Reductions
NGO	Nongovernmental Organization
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
OG	Official Gazette
PAF	Population Attributable Fraction
PAH	Polycyclic Aromatic Hydrocarbon
PforR	Program-for-Results
PM	Particulate Matter
PM_{10}	Particulate matter with a diameter of 10 micrometers or less
$PM_{2.5}$	Particulate matter with a diameter of 2.5 micrometers or less
PPP	Purchase Power Parity
SAAAQMS	State Automatic Ambient Air Quality Monitoring System
SO_2	Sulfur Dioxide
SEI	State Environmental Inspectorate

VOC	Volatile Organic Compound
VSL	Value of Statistical Life
WHO	World Health Organization
WTP	Willingness to Pay

Executive Summary

Ambient Air Quality in North Macedonia

Air pollution is a significant problem in cities and urban centers in the Republic of North Macedonia. This report is one in a series of three reports on air quality management (AQM) in Bosnia and Herzegovina, Kosovo, and North Macedonia. It examines the nature and magnitude of ambient air pollution (AAP) in North Macedonia. It provides estimates of the health burden, and economic cost associated with the health impacts, of AAP, that is, particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$) in North Macedonia. It also analyzes the roles of various sources of $PM_{2.5}$ emissions on ambient air quality in North Macedonia at the national level. The institutional and policy framework for AQM in the country is examined, including contributions of other development institutions in supporting North Macedonia's efforts to address air pollution. Furthermore, the report presents experiences of selected countries that have applied different policy, investment, and technical interventions for air pollution, prevention, reduction, and abatement. Finally, it provides recommendations for reducing air pollution in North Macedonia.

People in North Macedonia and living in the Balkans and Eastern Europe are typically breathing more toxic particulate air pollution than their neighbors in Western Europe. This is due to fewer air pollution reduction policies and more solid fuel heating and cooking (meaning many more residential wood and coal stoves) in Eastern European and Balkan countries compared to the rest of Europe. Western Europe has mostly moved away from coal-fired power plants (or at least has pledged to reduce coal consumption to meet climate goals), but in the Balkans and in Eastern Europe they are still widely in use. In fact, the Balkan region is home to many coal and lignite-fired units and to 7 of the 10 most polluting coal-fired power stations in Europe.

Health Burden and Economic Cost of Pollution in North Macedonia

This report estimates that about 1,600 people die prematurely every year as a result of exposure to AAP ($PM_{2.5}$) in North Macedonia. About 21 percent of this burden is carried by the capital city, Skopje. The total health burden is about twice as high as the burden in neighboring Kosovo. About 80 percent of the total number of AAP-related deaths are from cardiovascular diseases, of which about 95 percent 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.

The estimated 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 percent of gross domestic product (GDP) in 2016. The economic cost associated with health damage from AAP in North Macedonia is on average US$750 million, equivalent to 6.9 percent of GDP in 2016. 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 actually higher. Of the 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. This study updates the cost estimates provided by the World Bank Green Growth study (World Bank 2014), by incorporating updates related to improvements in air quality monitoring, exposure and background mortality data in North Macedonia, and methodological advances for health impact valuation since the previous study.

To better understand health impacts of AAP on its population, North Macedonia needs to strengthen capacity for conducting health impact assessments and improve statistics on disease-specific mortality attributable to AAP and availability of morbidity data attributable to AAP for specific diseases, age groups, and locations. The government should strengthen the capacity of public health institutions to conduct routine health impact assessment, notably from AAP. Furthermore, geographical coverage of reporting of AAP-related mortality by cause should be broadened to ensure that the most polluted areas are included. Reporting of mortality by cause would also facilitate international comparisons, that is, between North Macedonia and other countries that are at various stages of progress in tackling AAP. Data such as bronchitis prevalence for children, chronic obstructive pulmonary disease (COPD) in adults, hospital admissions for cardiovascular and respiratory illness, and lost workdays should be collected more extensively throughout the country to support analysis of morbidity associated with exposure to AAP.

Key Sources of $PM_{2.5}$ Exposure

Source apportionment analysis conducted in this report 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. Further analysis would be needed to better understand the role of other sources and hot spots, which could be more important at the local level. This study provides a first quantitative national-level examination of sources of $PM_{2.5}$. Additional sources of exposure to $PM_{2.5}$ include energy, industry, agriculture, and transport. Being a national-level source apportionment study, this report recognizes that contributions of specific sources may vary by geographical area and that pollution may be more localized in hot spots with some sources being more dominant than others. To better understand the source structure at the local level, for example, in a city, urban area, or hot spot, specific source apportionment studies will be needed and require comprehensive and accurate emissions inventories and reliable air quality monitoring data.

At the national level, the dominant share of $PM_{2.5}$ pollution originates within the geographical boundaries of North Macedonia, which underscores the need for the government to take concerted and committed action to tackle air pollution. The contribution of transboundary sources (about 30 percent) to AAP in the country is considerably less than domestic sources. The advantage of this is that the country has direct control over the selection, implementation, and timelines for the actions that need to be taken to achieve a significant impact in improving ambient air quality. Collaborative or regional approaches will, however, be needed to address transboundary pollution.

Unlike Kosovo and Bosnia and Herzegovina, North Macedonia has developed a national emissions inventory that appears complete and reports all key sources of pollution but needs to strengthen inputs, notably for residential and transport sectors. The country regularly submits a national inventory to the Convention on Long-Range Transboundary Air Pollution (CLRTAP). While the inventory provides a good basis for understanding the roles of different sources in ambient air quality, a few areas of the inventory can be strengthened, notably in the transport sector. There is a need to validate the consistency of transport data used in the inventory, cover all pollutants, including black carbon (BC), and further advance inventory development methods to capture context-specific features of important local emission sources.

For the residential sector, it is important to improve statistics on the use of fuelwood in the country, analyze typical quality of fuelwood in use in the country, and strengthen information on types of combustion technology used in the country.

North Macedonia has established a considerable air quality monitoring network. Given the significant health impacts and cost of AAP, it is important to expand monitoring of health damaging $PM_{2.5}$. Most of the 17 stations within North Macedonia's air quality monitoring network monitor particulate matter with a diameter of 10 micrometers or less (PM_{10}) concentrations, while monitoring of $PM_{2.5}$ is not as established. Results from limited trend analysis of monitoring observations conducted in this study indicate that several sources contribute to particulate matter (PM) pollution in urban areas. In addition to household sources, vehicles and road dust could also be important contributors. Furthermore, locations of some monitoring stations could be examined to ensure that they capture the influence of major industrial emissions. In addition, human and financial resources to ensure reliable operation and maintenance of monitoring stations need to be strengthened. Efforts could be taken to improve meteorological observational data outside of Skopje.

Furthermore, given the common practice of burning solid fuels in the country, North Macedonia could expand monitoring efforts to routinely include measurement of chemical species and constituents of PM such as elemental carbon, organic carbon, sulfates, which are associated with combustion processes and with adverse effects on human health. In addition, monitoring efforts should include measurement of precursors of $PM_{2.5}$ including sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and non-methane volatile organic compounds (NMVOC); BC, which is a constituent of PM and is also a climate warmer; and air toxics such as lead.

$PM_{2.5}$ emissions are not expected to decline markedly under existing policies due to the combustion of fuelwood in household stoves and boilers. If effectively enforced, existing environmental and air quality policies are expected to deliver a strong decline in the emissions of SO_2 and NO_x mainly due to legislation for large combustion plants but will not have major impacts on primary $PM_{2.5}$ emissions, as current energy projections do not foresee major shifts away from fuelwood burning in households.

Existing policies should lower concentrations of ambient $PM_{2.5}$ in large parts of the country but they will mostly remain higher than the health-based World Health Organization (WHO) guideline value. Pollution hot spots will remain such as in the northwestern and southern parts of the country and ambient concentrations could reach about 2–3 times the guideline values.

It is technically feasible to bring ambient $PM_{2.5}$ concentrations in most of the country to close to WHO $PM_{2.5}$ guideline value. However, it would require urgent action by the government and households. The relevant measures would require (a) early compliance of all new household stoves and boilers burning fuelwood with the stringent standards of the Ecodesign Directive of the European Union (EU), (b) replacement of the oldest existing installations, and (c) assurance of adequate quality of fuelwood which includes burning of dry fuelwood and proper storage of fuelwood. Such changes would require strong financial and governance mechanisms for their realization.

Policy and Institutional Aspects of Air Quality Management in North Macedonia

The Government of North Macedonia has made significant efforts to develop a comprehensive legal framework for ambient air quality that is harmonized with European legislation. Achieving sustained reductions in air pollution will, however, require further government commitment, dedicating significantly higher resources, and building capacity at different levels. Agencies responsible for AQM-related 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 of AQM including data analysis, reporting and management, chemical analyses, atmospheric modeling, and health impact assessment. Organizations such as North Macedonia's Environmental Information Center (MEIC), within the Ministry of Environment and Physical Planning (MEPP), which perform extensive AQM functions, and public health institutions, which are responsible for assessing the health burden of AAP, need to be properly resourced.

To effectively address the air pollution problem, there is need to take action, including strengthening the legal framework and monitoring network in specific areas and improving staffing levels and enforcement efforts. Although it is not a requirement of the EU Directive on ambient air quality and cleaner air for Europe, the government could introduce a standard for daily average ambient $PM_{2.5}$ concentration in accordance with the WHO air quality guideline value (25.0 μg/m^3), or corresponding interim targets (75.0 μg/m^3, 50.0 μg/m^3, 37.5 μg/m^3) as part of a phased approach for bringing ambient concentrations of $PM_{2.5}$ down. Another principal action is to strengthen the legal framework, focusing on specific instruments that reduce pollution from mobile sources, large stationary sources, and household heating. North Macedonia could also strengthen the use of economic instruments for AQM. In the area of capacity, there is a need to adequately staff organizations with responsibilities for AQM and develop an institutional structure to ensure ongoing evaluations of AQM policies and interventions. Giving more voice and information to the public and stakeholders is also an important area for action. Regarding enforcement, there is a need to expand the number of inspectors and provide them with training and resources to conduct field investigations, and there is also a need for clarifying sanctions for noncompliance, increasing fines, and expanding the range of sanctions in particular for large emitters of air pollution.

The government might revise the current organizational structure to incorporate units that are specifically dedicated to developing, implementing, monitoring, and evaluating air quality laws, policies, programs, and projects. Many of these responsibilities have been assumed by MEIC, but staff capacity is overstretched to fulfill this role in addition to its formal mandate related to environmental information. The organizational structure requires specialists who can carry out a range of actions, including monitoring, permitting, enforcement, and planning. Recruiting staff with the necessary expertise and background will be paramount to ensure that the MEPP can fulfill its responsibilities.

Strengthening institutional capacity to enforce existing air pollution limits is another pressing priority. As of 2015, a total of 19 inspectors were responsible for enforcing all environmental laws at the national level. Resource constraints are even more evident at the municipal level, leading to individuals being responsible for wide-reaching tasks that require multiple people including various inspections, issuance of permits, and other documentation. Sustained, higher resource allocation for enforcement and strong political will be key to improve enforcement of existing air quality laws and regulations. In addition to increasing the number and capacity of environmental inspectors, the government may incorporate other approaches to increase environmental compliance, for example, public disclosure schemes to generate social pressure against violators and judiciary processes.

Interventions to Reduce Exposure to Ambient Air Pollution

Addressing air pollution effectively in North Macedonia will require interventions policy, institutional and investment interventions in various sectors, and sources that affect air quality. Some interventions that the government may consider are described in the following paragraphs.

Residential. In 2017, the government announced that coal heating would be banned by 2020. While this is a positive step, the use of dirty fuels is a socially sensitive issue: a large share of the population cannot afford cleaner sources of heating. Given the severity of air pollution from these sources, the government could start with implementing a pilot program to substitute traditional stoves with more efficient ones in the short term. Lessons from such a pilot and other existing initiative could be considered to inform the development of a possible large-scale program stove replacement program. This would help reduce emissions from domestic heating while medium- to long-term options (for example, expanding district heating) can be developed. In many countries, these types of programs have been implemented, including targeted subsidies for project beneficiaries who cannot afford to pay the full costs of substituting their stoves with cleaner alternatives. In addition, public awareness campaigns should support stove replacement programs to facilitate adoption of cleaner stoves by households.

Mobile sources. About half of the passenger cars and buses in North Macedonia belong to the high emission category (Euro 0) with no emission control technology. The existing framework in North Macedonia contemplates the verification of mobile sources' compliance with the rulebook on the technical conditions of vehicles during the process for each vehicle's registration and inspection. In reality, these inspections have not helped reduce vehicle emissions especially associated with aging and growing fleets. The government could consider interventions such as (a) promoting lower sulfur content fuels; (b) implementing vehicle scrappage programs to replace older, polluting vehicles with newer, less polluting vehicles; (c) promoting conversion of vehicles through technological measures and financial incentives; (d) strengthening vehicle inspection and maintenance programs; and (e) strengthening enforcement of measures to reduce importation of older, polluting vehicles.

Stationary sources. The results of the national level source apportionment analysis conducted in this report indicate that contributions of stationary air pollution sources such as power plants and industry will decrease with time. Strong financial and governance mechanisms will be needed even under a maximum mitigation scenario to ensure that the marked declines occur. Ongoing efforts to ensure that large polluters—particularly in production of ferroalloys, cement, iron and steel, and others—adopt plans to gradually reduce their emissions and comply with environmental standards should be continued and strengthened, including by requiring installation of pollution abatement equipment and emissions control technology in production facilities. The government could provide financial incentives for smaller industrial undertakings to strengthen AQM. In addition, efforts to reduce air pollution should incorporate the use of sanctions for polluters that exceed their approved emission level, and sanctions should be clear and commensurate with the damage caused by polluters. Furthermore, the National Program for Gradual Reduction of the Quantities of Emissions of Certain Pollutants (2012–2020) currently focuses on abatement of acidification, human and vegetation exposure to ground-level ozone (O_3), and soil eutrophication. The program is being revised for the period 2016–2030 and could incorporate PM, including $PM_{2.5}$, which is currently not covered.

Learning from International Experience in Tackling Air Pollution

Addressing air pollution effectively requires strategic, integrated approaches and solutions that are appropriate to the specific city or geographical context and various sectors. A single sector or institution is unable to solely undertake the extensive work that is involved in AQM given its cross-cutting nature. Experiences from other countries that are making progress in tackling air pollution show that an integrated approach is required. By supporting these countries, the World Bank has demonstrated its ability to play an integrative role by bringing together and fostering dialogue between, and engagement of, various national and international stakeholders including different sectors of the economy, think tanks, academia, other development partners and by facilitating crucial analytical work to inform investments and policy and institutional actions for AQM.

The design and implementation of economically effective interventions to successfully reduce air pollution must be underpinned by a sound foundation of analytical work to inform the identification and selection of priorities and interventions and to set realistic and achievable air quality targets. As may be seen from the Peru and Mongolia examples, such analytical work also provides a platform around which various relevant stakeholders, including the government (across different sectors and different levels of government), think tanks, academia, private sector, and donor agencies, can engage and come to informed conclusions about possible interventions and implementation of an appropriate air pollution reduction program. The government could consider setting targets for ambient air quality concentrations of $PM_{2.5}$ and understanding how various pollution contributors can engage in actions to achieve the set target.

Conducting in-depth analytical work is often time-intensive and could span several years, requiring adequate budgetary resources. It is recognized that in many contexts, the severity of air pollution and its health impacts as well as public pressure on government and city officials to act may call for interventions in the immediate to short term to reduce air pollution. In such cases, a city could consider applying reasonable interventions and policy options that would help alleviate air pollution in the short term such as restricting pollution from known stationary sources or traffic restrictions. However, such short-term actions are unlikely to be able to effectively reduce air pollution in the long term, particularly where air pollution sources are many and varied. Thus, short-term actions should not replace a strategic and integrated approach informed by rigorous analytical work and engagement of various relevant stakeholders across different sectors (for example, environment, energy, transport, economy, agriculture), development partners, academia, and others to inform design and implementation of economically effective interventions for sustained or long-term air pollution reduction.

The government, together with neighboring countries, could establish a knowledge platform for collaboration on transboundary air pollution. Although most of the pollution in North Macedonia is from domestic sources, the transboundary contribution is important at 30 percent. To maximize the synergies between similar or shared air quality-related problems, the Government of North Macedonia could consider setting up, together with neighboring Balkan countries, a Balkan Knowledge Platform on transboundary air pollution. The knowledge platform could begin with coordination and knowledge sharing on technical aspects related to transboundary air pollution and gradually broaden the scope to collaboration on measures to address transboundary pollution based on experience and knowledge gained through interaction on the platform.

Benefit-cost analysis should be used to provide an informed basis for prioritizing and selecting interventions to reduce air pollution from different sectors. The interventions for tackling air pollution in different sectors are generally well-known, for example, promoting cleaner fuels and implementing district heating and transportation interventions. However, it is important that economically effective interventions are selected, which have a benefit-to-cost ratio greater than 1. In other words, the health benefits of an intervention, that is, avoided cost of premature mortality and morbidity, should be greater than the cost of implementing the intervention. It is recognized that such analysis should consider existing policy and operational constraints that could foreclose or limit the implementation of certain air pollution reduction interventions.

The experiences of different cities around the globe show that in addition to technical interventions, a menu of instruments, including market-based, economic, and command-and-control instruments, are needed to effectively reduce AAP. Examples from Mongolia, Peru, and China illustrate the types of interventions that have had a strong impact on reducing air pollution in those places and may provide useful lessons for North Macedonia as it strives to reduce air pollution. Cities in the aforementioned countries have successfully used a variety of instruments in their efforts to reduce air pollution, including market-based instruments, economic instruments, command-and-control instruments, investments in technical interventions, and policy and institutional reforms.

It is important that strategies and interventions to reduce air pollution do not disproportionately burden poor and vulnerable groups of people. Poor people are more likely to drive older, polluting vehicles. Poor people are also more likely to burn cheap and highly polluting fuels for domestic purposes. Therefore, policies that prohibit the use of old, polluting vehicles in favor of newer, clean vehicles could incorporate financial or other suitable incentives for poorer people to comply with the policies. Similarly, programs to promote replacement of polluting stoves with clean, efficient stoves should incorporate incentives that will help low-income households' transition to burning cleaner fuels. It would be important to consider distributional and social impacts of a ban on coal heating, if implemented, on affected populations in different income groups. Poverty and social impact analysis could be used to understand distributional impacts of policies to reduce air pollution to ensure that the poor and vulnerable are not disadvantaged by actions resulting from those policies.

Many development partners are supporting North Macedonia's efforts to reduce air pollution and to maximize their support sustained government investment is needed. There is a need to take stock of the outcomes of these activities and to identify opportunities where investments and policy and institutional actions can scale up impacts on air quality supported by appropriate financing mechanisms. The work of several development partners including the European Commission; the Government of Germany, United Kingdom, Sweden, Switzerland; and others has been instrumental in advancing progress on AQM in North Macedonia. Nevertheless, the air pollution problem is significant and cannot be resolved without sustained government commitment combined with targeted policy actions; strong institutions at all levels of government, particularly at the local level where the impacts are most felt; and sound planning and investments underpinned by rigorous analytical work. Stocktaking of the outcomes of ongoing donor-supported activities and identification of opportunities and financing mechanisms should be coordinated among donors and conducted in collaboration with the government.

Recommendations for Air Quality Management in North Macedonia

The key recommendations of this report are summarized in Table ES1.

Table ES.1. Summary of recommendations to strengthen AQM in North Macedonia

Recommendation	Time Frame
Legal and policy framework	
Strengthen the legal framework, focusing on specific instruments that reduce pollution from mobile sources, large stationary sources, and household heating.	Short to medium term
Strengthen the legal framework by adopting and implementing diverse air pollution management instruments, including economic and market-based instruments.	Medium term
Introduce standard for daily average ambient $PM_{2.5}$ concentration.	Short to medium term
Air quality, emissions and health data and analysis	
Strengthen the air quality monitoring network to provide reliable time series data on pollutants, notably $PM_{2.5}$.	Short term
Expand air quality monitoring to include chemical constituents and species of PM such as elemental carbon, organic carbon, sulfates associated with combustion processes; $PM_{2.5}$ precursors including SO_2, NO_x, NH_3, and NMVOC; BC; and heavy metals such as lead.	Short to medium term
Conduct baseline measurement exercises: (a) polycyclic aromatic hydrocarbons (PAHs) measurements in one urban location in each zone and agglomeration to define further measurement needs and potential interventions and (b) one-year campaigns in selected hotspot or industrial locations to estimate ambient concentrations of heavy metals.	Short to medium term
Improve meteorological observational data outside of Skopje, background monitoring data, and a comprehensive inventory of pollutants to improve dispersion modeling.	Medium to long term
Strengthen inventories for residential and transport sectors including (a) transport - validate data consistency, address all pollutants including BC, strengthen inventory development methods to capture local context and (b) residential - improve fuelwood statistics, analyze typical fuelwood quality, and analyze information on combustion technology in use in the country.	Short to medium term
Strengthen capacity to conduct health risk assessment.	Short to medium term
Strengthen health statistics to allow estimation of AAP-related mortality by cause	
Improve site-specific collection and reporting of morbidity data attributable to AAP for specific diseases and age groups.	
Reducing pollution from different sectors/sources	
Residential. (a) Pilot substitute traditional stoves with more efficient ones and build on lessons learned and experience to date to develop a large-scale program; (b) put in place targeted financial incentives to help poor households adopt clean, efficient, stoves; and (c) implement public awareness campaign to promote stove replacements.	Short to medium term
Mobile sources. (a) Promote lower sulfur content fuels; (b) implement vehicle scrappage programs to replace older, polluting vehicles with newer, less polluting vehicles; (c) promote conversion of vehicles through technological measures and financial incentives; (d) strengthen vehicle inspection and maintenance programs; and (e) strengthen enforcement of measures to reduce importation of older, polluting vehicles.	Medium to long term
Stationary sources. (a) Strengthen enforcement to ensure that large polluters develop and adopt plans to gradually reduce their emissions and comply with environmental standards, which should be continued and strengthened; (b) financial incentives for small industrial facilities to undertake air pollution control measures; (c) use of sanctions that are clear and commensurate with the damage caused by polluters that exceed their approved emission levels; and (d) incorporate $PM_{2.5}$ in ongoing revision of National	Short to medium term

Recommendation	Time Frame
Program for Gradual Reduction of the Quantities of Emissions of Certain Pollutants for 2016–2030.	
Transboundary sources. Establish, together with neighboring countries, a technical knowledge platform on transboundary pollution.	Short to medium term
Organizational framework	
Adequately staff organizations with responsibilities for AQM.	Short term
Revise the current organizational structure to incorporate units that are specifically dedicated to developing, implementing, and monitoring and evaluating air quality laws, policies, programs, and projects.	Short term
Develop an institutional structure to ensure ongoing evaluations of AQM policies and interventions.	Medium term
Public participation	
Establish a multistakeholder air quality advisory board to periodically discuss the development, implementation, and evaluation of actions to improve air quality.	Short term
Support public interest advocacy through legal associations, establish environmental law clinics at universities, and provide training and disseminating specific materials for targeted audiences.	Medium term
Enforcement	
Expand the number of inspectors and provide them with training and resources to conduct field investigations.	Short term
Strengthen enforcement by clarifying sanctions for noncompliance, increasing fines, and expanding the range of sanctions.	Medium term

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF BOXES

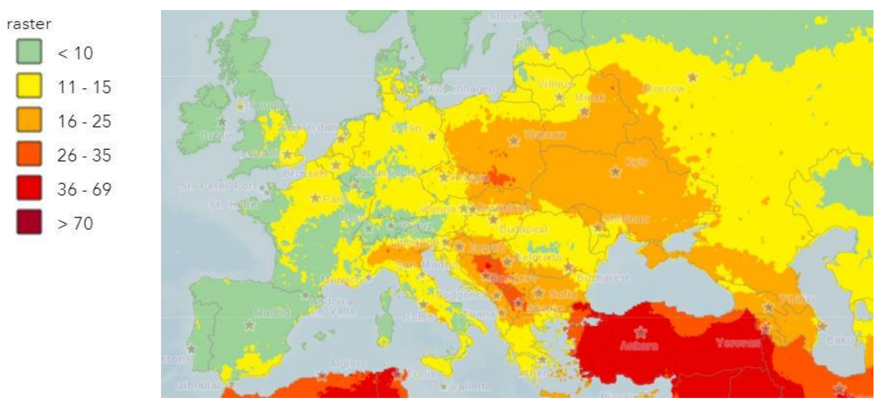
Chapter 1. Ambient Air Quality in North Macedonia

1.1 Background

People living in the Balkans and Eastern Europe are typically breathing more harmful air than their neighbors in Western Europe (Figure 1.1). The burning of solid fuels for domestic heating and cooking, wide use of coal-fired power plants, industry, and aging vehicle fleets are contributory factors to elevated concentrations of ambient air pollution (AAP).

In North Macedonia, large numbers of people are exposed to ambient concentrations of fine particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$) which exceed the World Health Organization (WHO) air quality guideline value of 10 μg/m^3 and the less stringent European Union (EU) limit value of 25 μg/m^3 (Figure 1.1). The detrimental health effects of $PM_{2.5}$ are well documented, and it is one of the world's leading causes of illness and death, associated with lung cancer, ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), and respiratory disease. In addition, particulate matter (PM) comprises black carbon (BC), which is formed from incomplete combustion of fossil fuels, wood, and other fuels, and has climate warming properties.

Figure 0.1. Locations where annual mean $PM_{2.5}$ (μg/m^3) meet or exceed WHO guidelines (2016)



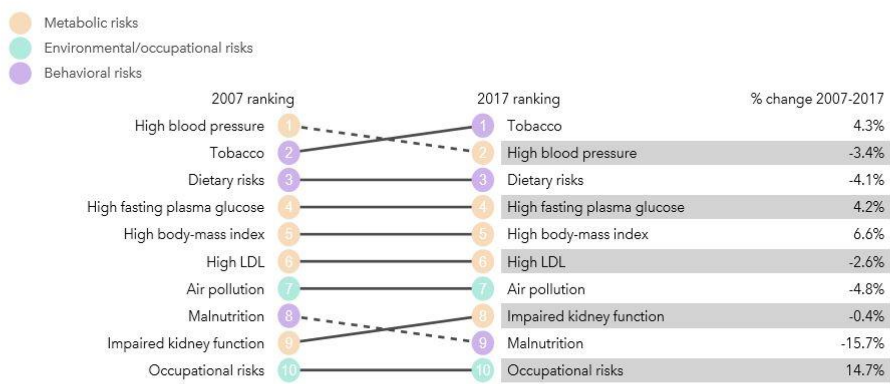
Source: WHO 2018, http://maps.who.int/airpollution.

According to the Institute for Health Metrics and Evaluation (IHME), an independent global health research center, air pollution is the leading environmental risk factor that drives most deaths and disability combined in North Macedonia (Figure 1.2). In the capital city, Skopje, hourly average concentrations of 800 μg/m^3 and 500 μg/m^3 have been measured for particulate matter with a diameter of 10 micrometers or less (PM_{10}) and $PM_{2.5}$, respectively (Anttila et al. 2016). Ambient concentrations of PM are significantly higher during winter months due to increased emissions, particularly from burning of solid fuels for heating in homes and other buildings coupled with adverse meteorological conditions limiting atmospheric dispersion.

The frequency of high pollution incidents results in a high number of exceedances of national ambient air quality standards. Widespread frustration about air pollution has led to various forms of citizen pressure including public protests, public debates on air pollution, and other calls for local authorities to act. The first National Action Plan for Open Government Partnership (OGP) 2012–2014 introduced the policy to encourage the publishing of open data and established the official portal for open public data. In response to high pollution incidents, the government has taken emergency measures. In the winter of 2017–2018, alarmingly high levels of air pollutants prompted the government to announce a series of emergency measures, including making public transportation freely available in the cities Skopje and Tetovo, banning heavy vehicles from entering city centers, and exempting pregnant women, people with chronic illnesses, and people over 60 years of age from work (AP 2018).

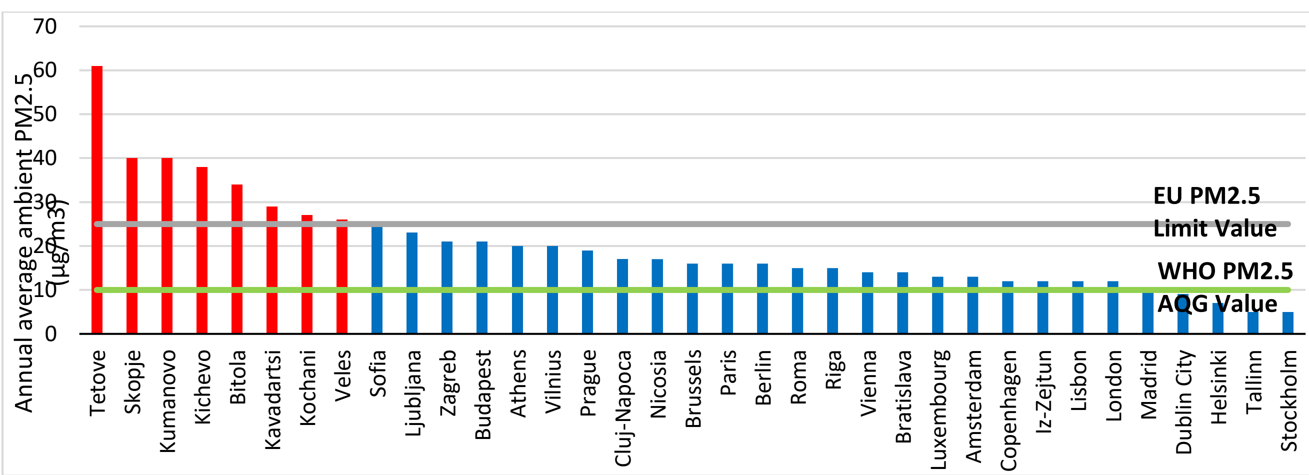
Compared to other cities in Europe, cities in North Macedonia such as Tetovo, Skopje, and others have substantially higher ambient concentrations of air pollution (Figure 1.3). While pollution levels have decreased since the 1990s, air pollution has reached health threatening levels in most urban locations across North Macedonia, particularly during winter months (FMI and MEPP 2017). Continuous monitoring in selected North Macedonia's cities found $PM_{2.5}$ hourly concentrations of up 800 µg/m^3, that is, more than 30 times higher than the 24-hour mean set by the WHO guidelines 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, while PM_{10} levels were almost five times the WHO guidelines. In the capital city Skopje, annual average concentrations of ambient $PM_{2.5}$ and PM_{10} are about four times and more than three times higher, respectively, than the WHO air quality guideline values.

Figure 0.2. Risk factors that drive the most death and disability combined in North Macedonia



Source: IHME 2018, http://www.healthdata.org/macedonia.

Figure 0.3. Air pollution levels in North Macedonia's cities compared to other European cities ($PM_{2.5}$)

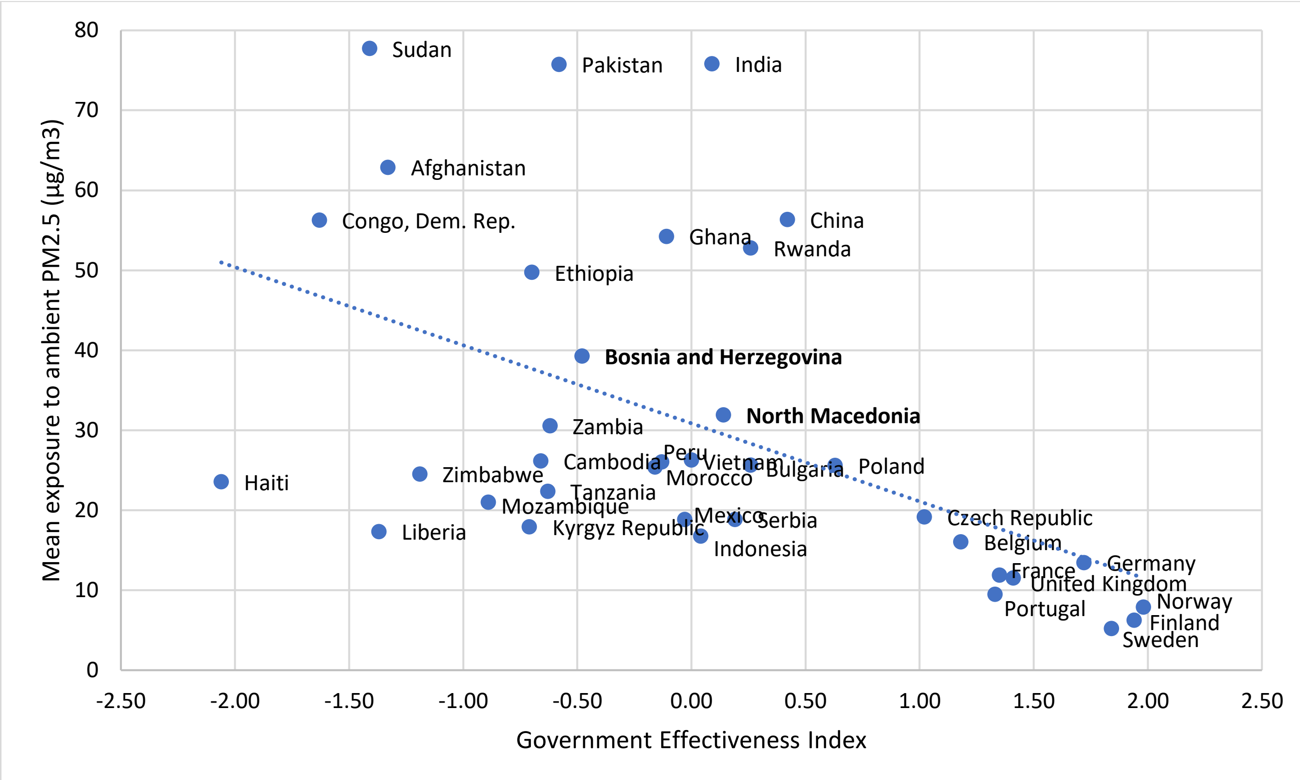


Source: WHO 2018, http://maps.who.int/airpollution.

North Macedonia is a candidate country to join the EU. The EU accession process provides an incentive to adapt legislation and learn from experience of other EU countries how air quality can be improved through emissions reduction from key sources of polluting air emissions. The government committed itself to the implementation of EU-related reforms. However, persistent shortcomings in the rule of law exist. On air quality, the legislative alignment is almost complete, but implementation remains weak. Specifically, the country should improve coordination between the government, central-level institutions, and municipalities to actively work toward air quality improvement. Furthermore, while North Macedonia has adopted the National Strategy on Environment and Climate Change, administrative capacities are insufficient and significant efforts are needed for implementation and enforcement (EC 2018). For potential accession to the EU, the countries in the region must, under the EU Industrial Emissions Directive, reduce emissions by 94 percent for airborne particulates, 90 percent for sulfur dioxide (SO_2), and 67 percent for nitrogen oxides (NO_x) by 2028.

Environmental quality indicators correlate with governance indicators such as government effectiveness, voice and accountability, political stability, regulatory quality, rule of law, and control of corruption (Figure 1.4). The World Governance Indicators, published annually by the World Bank, reflect institutional problems that are relevant to environmental quality management (World Bank 2018). The Government Effectiveness Index captures perceptions of the quality of public services, quality of the civil service, and the degree of its independence from political pressures, quality of policy formulation and implementation, and credibility of the government's commitment to such policies. Some of these governance issues are relevant to air quality management (AQM) and could be relevant to the institutional framework for AQM in North Macedonia. As can be seen, a positive correlation exists between government effectiveness and air quality. Western Balkan countries such as North Macedonia and Bosnia and Herzegovina have higher levels of AAP than some other countries with lower Government Effectiveness Indexes.

Figure 0.4. Government effectiveness and air pollution ($PM_{2.5}$)



Source: World Bank 2018.

1.2 Objectives of This Report

This report is one in a series of three reports on AQM in Bosnia and Herzegovina, Kosovo, and North Macedonia. It examines the nature and magnitude of AAP in North Macedonia. It provides estimates of the health burden, and economic cost associated with the health impacts, of AAP, that is, $PM_{2.5}$ in North Macedonia. It analyzes the roles of various sources of $PM_{2.5}$ emissions on ambient air quality in North Macedonia at the national level. The institutional and policy framework for AQM in the country is examined, including contributions of other development institutions in supporting North Macedonia's efforts to address air pollution. Furthermore, the report presents experiences of selected countries that have applied different policy, investment, and technical interventions for air pollution, prevention, reduction, and abatement. Finally, it provides recommendations for reducing air pollution in North Macedonia.

1.3 Methodology

Air quality assessment. This report provides an assessment of the ambient air quality status in North Macedonia based on desktop review of available data from the Ministry of Environment and Physical Planning (MEPP) and National Hydrometeorological Service, as well as reports and other information received from local consultants and relevant government counterparts.

Economic analysis of health effects of AAP. The environmental health and economic analysis relies on primary data obtained from statistical yearbooks in North Macedonia, as well as from North Macedonia MEPP and Ministry of Health primary data on air pollution and health, and various reports that summarize this information. The analysis also uses peer-reviewed publications from Western Balkans, as well as from global and European organizations. Quantification of health effects from air pollution is grounded in commonly used methodologies that link mortality of the population and exposure to pollution. The economic costs of these health effects are assessed using standard valuation techniques that present the economic value of the attributable mortality in monetary terms, based on economic indicators from North Macedonia.

Institutional and policy review. This report includes desk review of the institutional and policy framework for AQM in North Macedonia, including progress in transposing EU legislation, and key aspects of AQM such as monitoring, data management, and dissemination of air quality information that can inform strategies and interventions to reduce air pollution. It also summarizes the roles of organizations that are responsible for developing, implementing, monitoring, evaluating, and enforcing air quality legal and policy instruments. Based on information obtained from development partners active in North Macedonia, it also discusses how they are contributing to AQM efforts in the country.

Analysis of key sources of $PM_{2.5}$ exposure. Following a qualitative overview of sources of exposure to $PM_{2.5}$ in the country, this report provides a quantitative analysis of the source structure of $PM_{2.5}$ emissions for the first time in this region (covering Bosnia and Herzegovina, Kosovo, and North Macedonia) in a harmonized way, comparing model-calculated $PM_{2.5}$ concentrations with recent observations from local measurement networks as available and developing national-level source apportionments for ambient $PM_{2.5}$ for North Macedonia and the two other countries mentioned. The quantitative analyses were performed with the Greenhouse Gas-Air Pollution Interactions and Synergies (GAINS) model developed at the International Institute for Applied Systems Analysis (Amann et al. 2011). The model allows simulation of the impacts of policy actions that influence future driving forces (for example, energy consumption, transport demand, agricultural activities) and of dedicated measures to reduce the release of emissions to the atmosphere, on total emissions, resulting air quality, and a basket of air quality and climate impact indicators.

1.4 Analytical Value Added

This report provides analysis that adds to knowledge in the following areas:

1. Updated national-level assessment of health and economic damages from air pollution in North Macedonia, primarily from $PM_{2.5}$—the most detrimental air pollutant to health—and based on the most up-to-date methodologies
2. Development, for the first time, of a preliminary national-level source apportionment analysis for $PM_{2.5}$
3. Analysis of scenarios of $PM_{2.5}$ emissions, and ambient concentrations, from a baseline of 2015 up to 2030
4. Sharing of global experiences and lessons learned from interventions by other World Bank client countries to address AAP in key sectors
5. A basis to inform possible long-term engagement by the World Bank in supporting North Macedonia in tackling air pollution, considering efforts of other development partners

1.5 Ambient Air Quality in North Macedonia

Ambient air quality is assessed not only by the concentration of a pollutant but also by the number of times that the limit value for that pollutant is exceeded. Ambient air quality standards in North Macedonia are provided in Table 1.1 along with EU limit values and WHO guideline values. North Macedonia's air quality standards are aligned with EU air quality standards.

Table 0.1. Air quality limit values in North Macedonia as compared to the WHO guidelines and EU standards

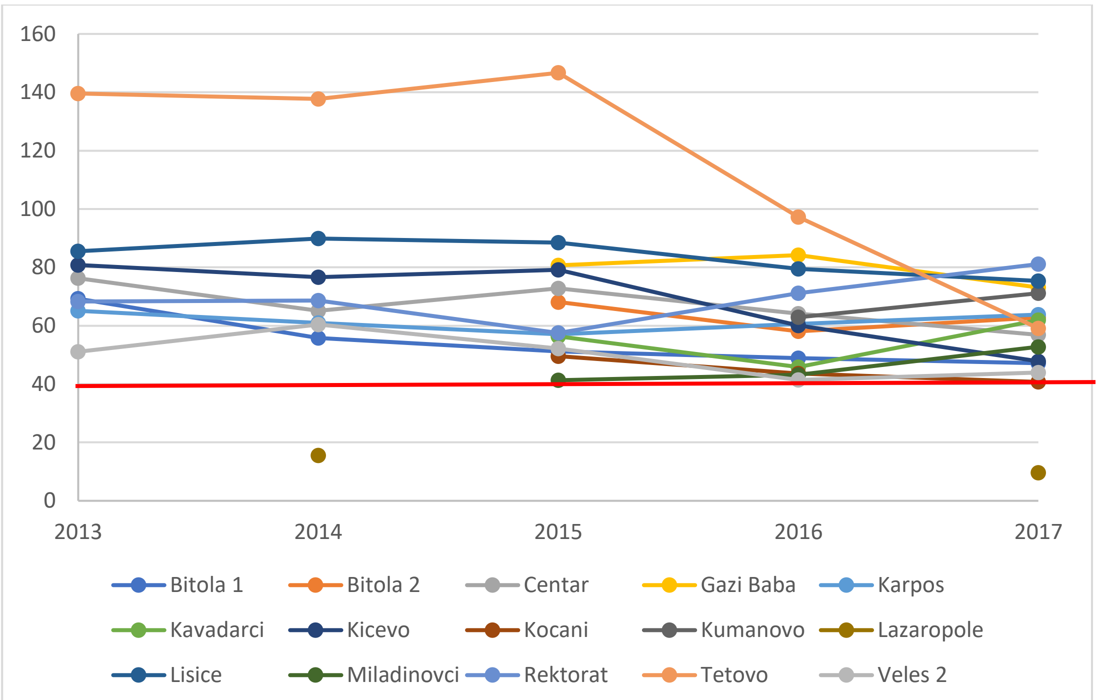
Pollutant		WHO air quality guidelines	EU air quality standards	North Macedonia AQ limits
PM_{10}	Annual mean	20 μg/m^3	40 μg/m^3	40 μg/m^3
	24-hour mean	50 μg/m^3	50 μg/m^3 (not to be exceeded more than 35 times a calendar year)	50 μg/m^3 (not to be exceeded more than 35 times a calendar year)
$PM_{2.5}$	Annual mean	10 μg/m^3	25 μg/m^3	25 μg/m^3
	24-hour mean	25 μg/m^3		Ozone
Ozone (O_3)	8-hour mean	100 μg/m^3	120 μg/m^3	120 μg/m^3
Nitrogen dioxide (NO_2)	Annual mean	40 μg/m^3	40 μg/m^3	40 μg/m^3
NO_2	1-hour mean	200 μg/m^3	200 μg/m^3 (not to be exceeded more than 18 times a calendar year)	200 μg/m^3 (not to be exceeded more than 18 times a calendar year)
SO_2	24-hour mean	20 μg/m^3	125 μg/m^3 (not to be exceeded more than 3 times a calendar year)	125 μg/m^3 (not to be exceeded more than 3 times a calendar year)
	10-minute mean	500 μg/m^3	350 μg/m^3 (not to be exceeded more than 24 times a calendar year)	350 μg/m^3 (not to be exceeded more than 24 times a calendar year)

Annual average PM_{10} concentrations recorded at air quality monitoring stations in North Macedonia during 2013–2017 are shown in Figure 1.5. Limit values are exceeded at most of the stations during this period except in Lazaropole, a regional background station. There is a slight decreasing trend in concentrations between 2013 and 2017 except Rektorat (traffic stations) and Miladinovci (industrial station) stations, where an increasing concentration trend is observed especially after 2015. Measured PM_{10} concentrations are about 1.5–2.0 times higher than limit values at most of the stations. At some stations even higher exceedances are observed (for example, in Tetovo station more than three times limit values observed in 2013–2015). Similar to annual averages, daily average concentrations of PM_{10} measured at most of the stations exceed limit values (Figure 1.6). Unlike annual average trends, however, there is a slight increasing trend in daily average concentrations measured at most of the stations except a few that show decreasing trend.

Number of days when the daily limit value is exceeded relative to the annual number of allowed exceedances is shown in Figure 1.7. Daily limit values are exceeded during almost one-third of the year. In Tetovo, up to 350 days of exceedances were recorded in 2015. In other words, there were only 15 days of that year in which air quality complied with limit values.

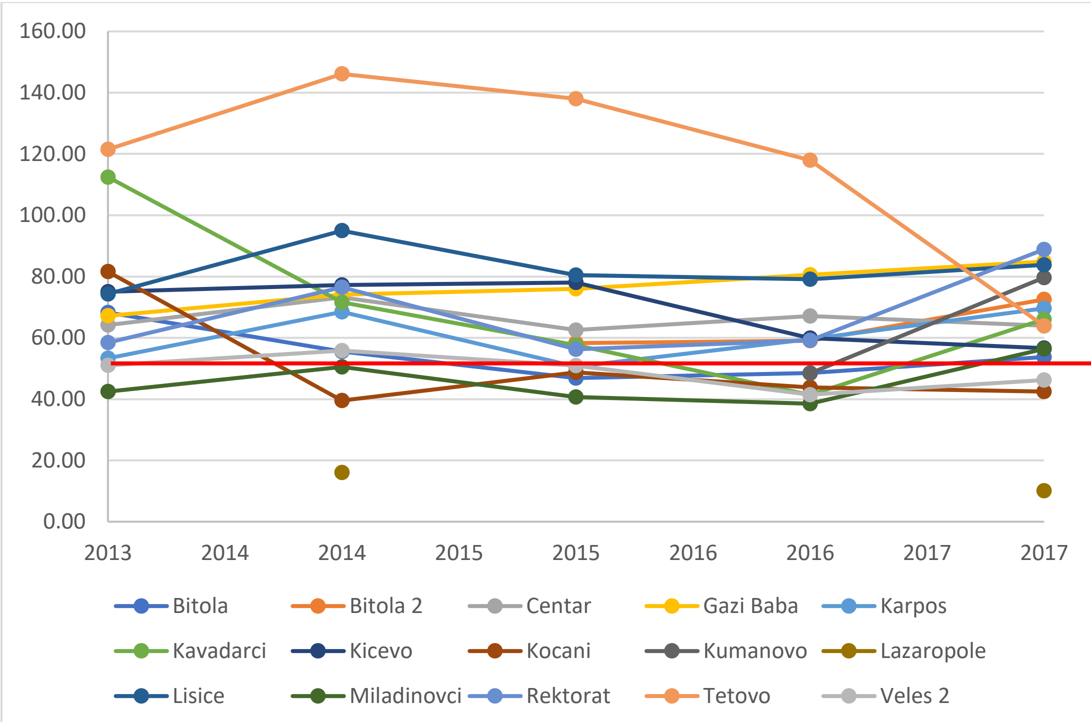
$PM_{2.5}$ concentrations are measured at two stations, namely Centar and Karpos, between 2013 and 2017 and results are provided in Figure 1.5 for annual averages. Bitola 2, Kumanovo, and Tetovo stations also have $PM_{2.5}$ data for 2017 but data completeness is poor (less than half of the data are missing); therefore, results for Centar and Karpos are presented in Figure 1.5. Annual average $PM_{2.5}$ concentrations measured at both stations are well above the annual limit value of 25 µg/m^3.

Figure 0.5. Annual average PM_{10} concentrations measured at monitoring stations (2013–2017)



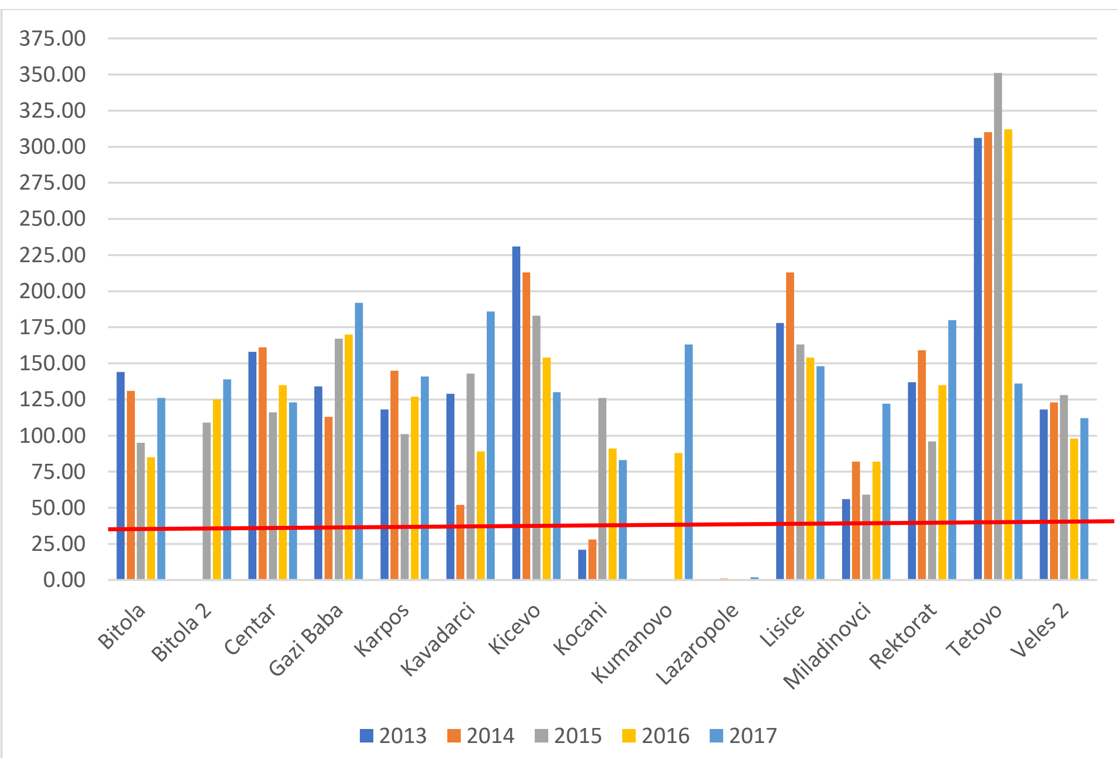
Note: Red line on the graph denotes annual average limit value of 40 µg/m^3.

Figure 0.6. Daily averages of PM_{10} concentrations measured at monitoring stations (2013–2017)



Note: Red line on the graph denotes daily average limit value of 50 µg/m³.

Figure 0.7. Number of exceedances of daily PM_{10} limit value of 50 µg/m³ by year

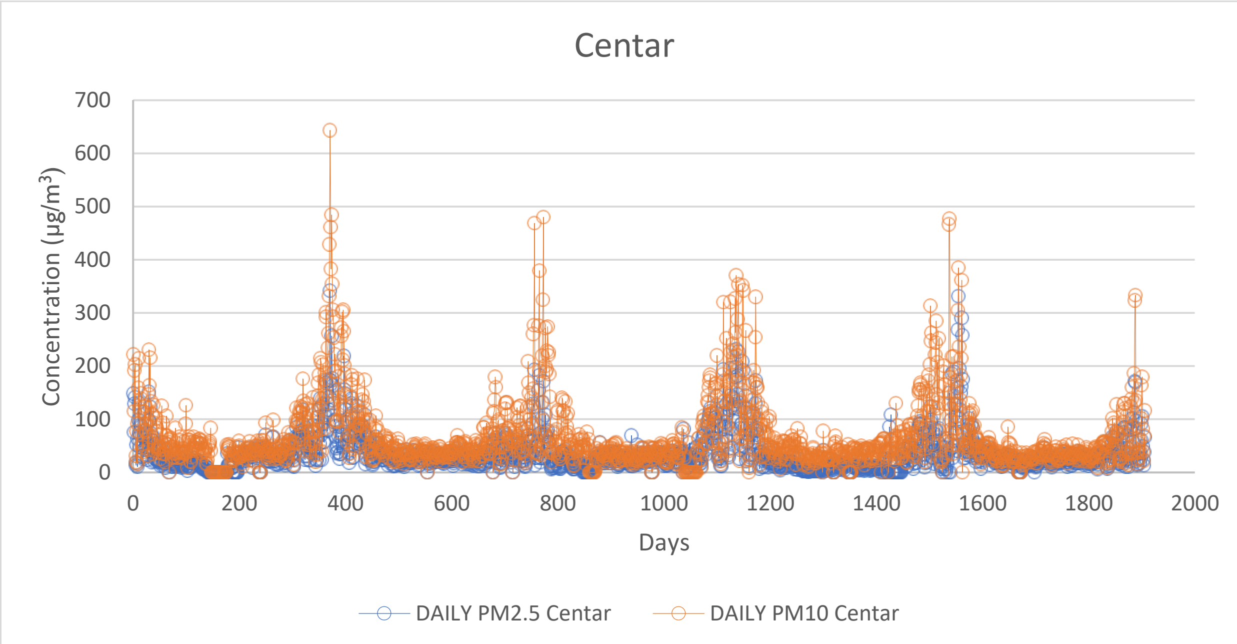


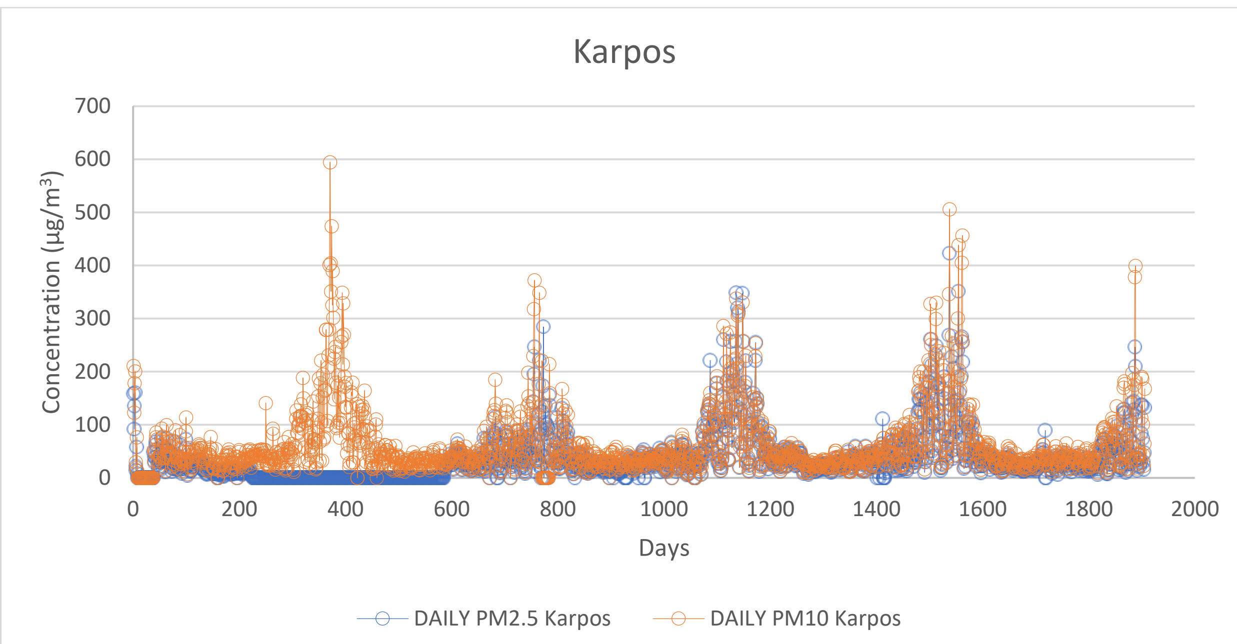
Note: Red line denotes maximum allowable number of exceedances of 35 days per year.

Long-term Air Quality Assessments and Trends

This study analyzed time series of $PM_{2.5}$ and PM_{10} data recorded at two stations—Centar and Karpos—between 2013 and 2017 (Figure 1.8). Most of the 17 stations within North Macedonia's air quality monitoring network monitor PM_{10} concentrations. Monitoring of $PM_{2.5}$ is not as established as for PM_{10}. Only two stations, Centar and Karpos, monitored $PM_{2.5}$ during 2013–2017. In addition, $PM_{2.5}$ concentrations were monitored at Bitola 2, Kumanovo, and Tetovo stations in 2017 but monitoring data are available for only half of the year at these stations. The results from Centar and Karpos stations reveal similar seasonal trends for both pollutants, with higher concentrations observed during winter than summer. Poor atmospheric mixing due to adverse meteorological conditions observed during winter is also a factor in the higher concentrations in this season. The similarity of trends could also be an indication that both pollutants are emitted from similar sources.

Figure 0.8. Daily average $PM_{2.5}$ and PM_{10} concentrations at Centar (top) and Karpos (bottom) stations (2013–2017)

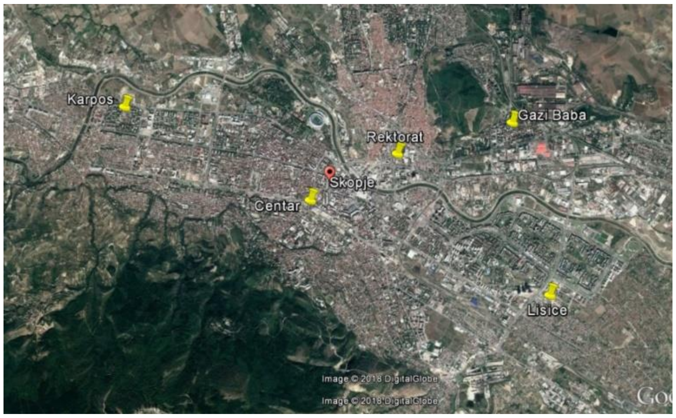




Air quality trend analyses provide information regarding effectiveness of measures that are already in place in achieving target limit values as well as insight regarding source and concentration relations depending on the location of monitoring stations. It is also important to record and assess ambient air quality data to evaluate compliance with air quality limit values set for human health and ecosystem protection purposes and to assess health impacts.

This study examined selected stations in Skopje to further understand air quality trends (Figure 1.9). These stations include (a) Centar and Rektorat - traffic stations; (b) Gazi Baba and Karpos - urban background/suburban stations; (c) Lisice - an industrial/residential station that is close to a major intersection; a cement factory is 1.2 km southwest of the station and a quarry at a distance of 1.8 km; (d) Miladinovci - an industrial station to monitor the air quality impact of the OKTA refinery. Out of these six stations, $PM_{2.5}$ concentrations are monitored only at Karpos and Centar stations.

Figure 0.9. Locations of air quality monitoring stations in Skopje



Source: Location of the monitoring stations received from the MEPP as of July 2018 and shown on Google Earth Map.

Effect of Meteorological Parameters

To investigate seasonal variations of PM_{10} concentrations measured at monitoring stations at Skopje, monthly average concentrations recorded between 2013 and 2017 are calculated and shown in Figure 1.10. The results show seasonal variations for other stations in North Macedonia to demonstrate influence of meteorological conditions. Monthly average PM_{10} concentrations show a distinct pattern with higher ambient concentrations during winter months (especially November, December, January, and February) and lower ambient concentrations during summer months. This might be due to enhanced atmospheric dispersion of air pollutants during summer months and poor atmospheric dispersion of air pollutants in winter months due to meteorological parameters.

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 (a) influencing atmospheric dispersion of pollutants via stability of the atmosphere and (b) wash-out of pollutants in the atmosphere via precipitation. Furthermore, atmospheric stability is influenced by temperature, wind speed, and inversion, among others. 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. Atmospheric stability shows seasonal variations, creating better atmospheric dispersion conditions for air pollutants during summer and lower atmospheric dispersion conditions for air pollutants during winter.

Temperature and wind data recorded at Karpos (urban background) station are plotted and shown in Figures 1.11 and 1.12. Karpos station was chosen as it is a background station and is not expected to be directly influenced by emission sources (although residential heating emissions might have an impact on pollution concentrations measured at these stations since it is located in a residential area). Figure 1.11 shows monthly average PM_{10} concentrations measured at Karpos station compared with inverse temperature data recorded at this station. PM_{10} concentrations show a similar trend with inverse temperature with higher concentrations recorded during cold months (November through February). Figure 1.12 shows monthly average PM_{10} concentrations measured at Karpos station compared with calm wind (that is, wind speed less than or equal to 1 m/sec) conditions. Higher PM_{10} concentrations are recorded during calm atmospheric conditions, indicating impact of poor atmospheric mixing on ambient concentrations.

Figure 0.10. Monthly average PM_{10} concentrations measured at monitoring stations (2013–2017)

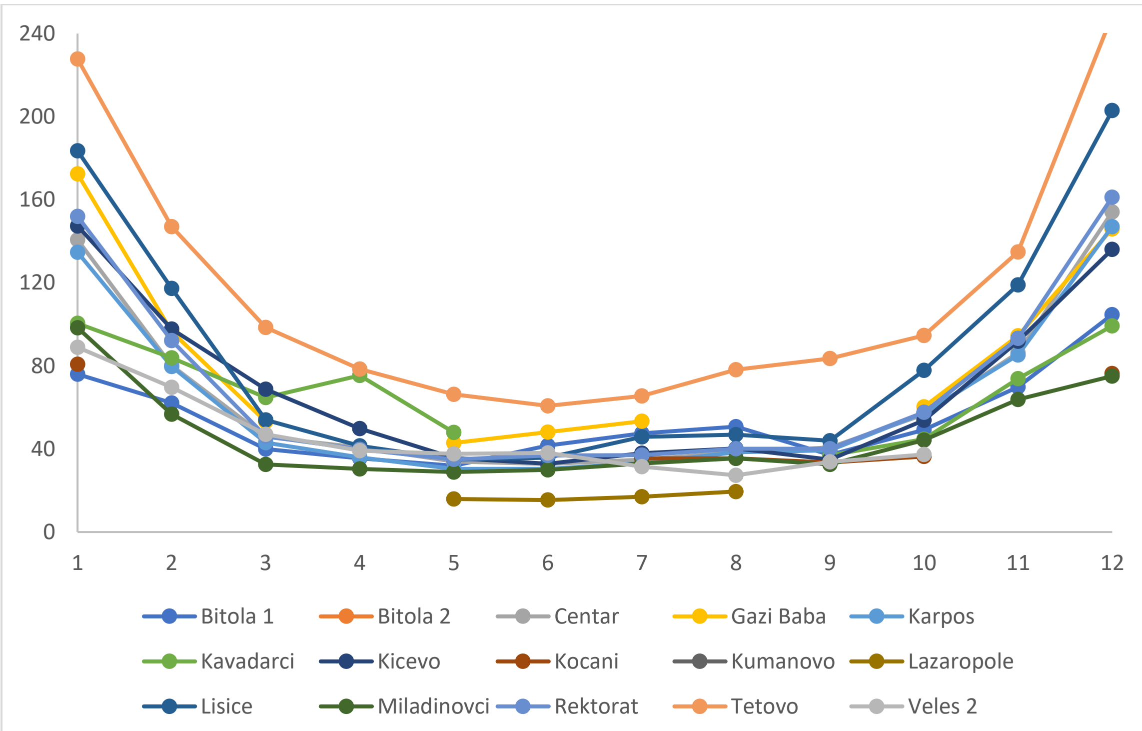


Figure 0.11. Monthly average PM_{10} concentrations measured at Karpos station compared with temperature data (2013–2017)

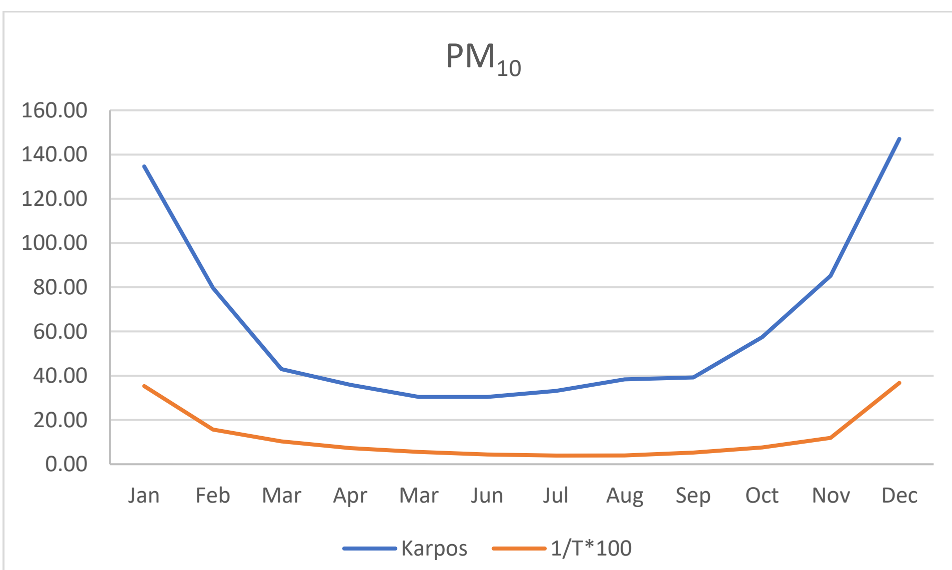
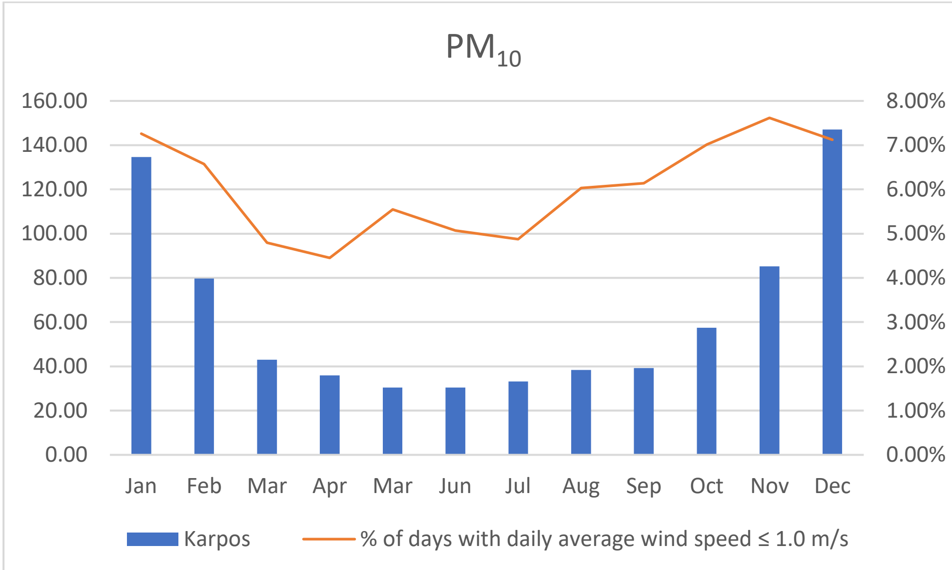


Figure 0.12. Monthly average PM_{10} concentrations measured at Karpos station compared with calm wind data (2013–2017)



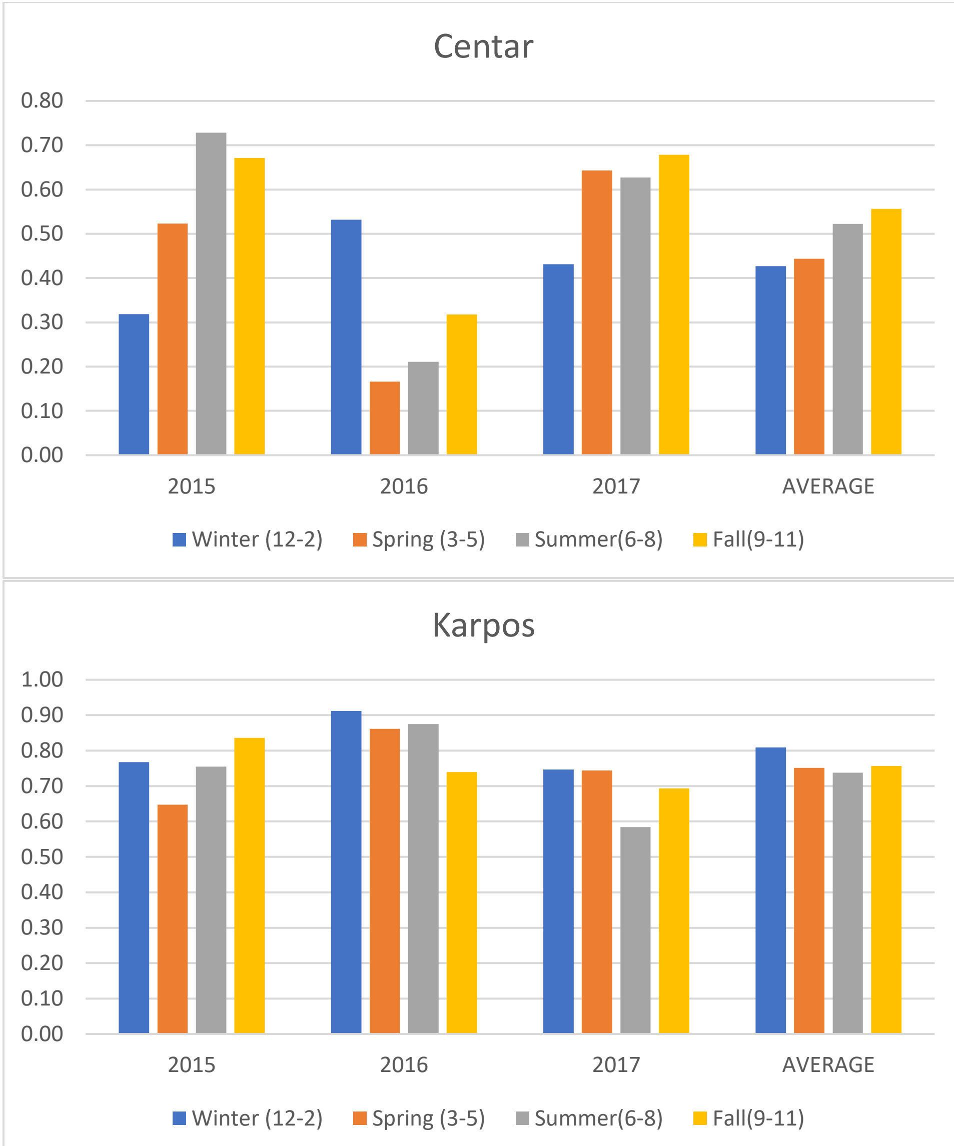
$PM_{2.5}/PM_{10}$ Ratio Analyses

The analysis of the $PM_{2.5}/PM_{10}$ ratio is useful in understanding how the fine proportion of ambient PM varies with time and can be indicative of pollutant sources. A $PM_{2.5}/PM_{10}$ ratio of about 0.5 is typical in urban areas and is indicative of contributions of both coarse and fine particles (Xu et al. 2017). Higher ratios of $PM_{2.5}/PM_{10}$ indicate abundance of particles from combustion sources. The $PM_{2.5}/PM_{10}$ ratio analysis can also serve a data quality control function.

$PM_{2.5}/PM_{10}$ values are computed for Centar and Karpos stations and shown in Figure 1.13. Seasonal $PM_{2.5}/PM_{10}$ values are presented for each data year available (that is, 2015–2017) as well as average of all data years (that is, 2015–2017). Centar and Karpos are used for this assessment since they are the only stations where both $PM_{2.5}$ and PM_{10} measurements are available in Skopje. For this assessment, the seasons (months) were winter (December–February), spring (March–May), summer (June–August), and fall (September–November).

Average $PM_{2.5}/PM_{10}$ ratios observed at these stations during the data period are about 0.5 and 0.7 for Centar and Karpos, respectively. Centar is in an urban traffic location and $PM_{2.5}/PM_{10}$ value of 0.5 is a typical urban value indicating contribution of both coarse and fine particle emissions such as road dust, resuspension, motor vehicle, and residential heating influencing this station. Karpos is an urban background/suburban station in a residential location. The higher contribution of finer particles is indicated by higher $PM_{2.5}/PM_{10}$ value (that is, 0.7) recorded at this station, suggesting the influence of fine particle sources such as residential heating and/or transport of pollution from other areas. $PM_{2.5}/PM_{10}$ values observed at Karpos station are slightly higher in winter than in other seasons indicating influence of both residential heating sources during winter as well as transport of emissions from other locations influencing concentrations measured at this station.

Figure 0.13. $PM_{2.5}/PM_{10}$ values measured at Karpos and Centar stations at different seasons (2015–2017)



1.6 Summary

AAP, notably $PM_{2.5}$, is a problem in cities and urban centers in North Macedonia. $PM_{2.5}$ and PM_{10} exceedances of EU/WHO standards in North Macedonia are widespread and deleterious to human health. Results from Skopje show that the most severe exceedances of ambient air quality standards occur during winter.

Analysis of trends in $PM_{2.5}/PM_{10}$ ratio for stations in Skopje indicates that in urban areas various sources of PM contribute to air pollution. Results from Centar and Karpos stations suggest that in addition to household sources, vehicle, road dust, and transport of emissions from other locations could be important contributors to AAP in urban areas. Emission inventories should be strengthened to reflect relevant sources.

A preliminary assessment based on desktop review indicates that the air quality monitoring network in North Macedonia is well established, but a few areas could be further strengthened. Further investigation and detailed assessment including site visits and stakeholder interviews are recommended to confirm these preliminary findings. Key findings and recommendations on air quality monitoring in North Macedonia based on this preliminary assessment are as follows:

- Monitoring stations are spread across in the country and their number seems to be adequate. Location of some of the monitoring stations could be further investigated as this preliminary assessment points out that some of the stations may not capture the influence of major industrial emissions on nearby residential areas. Furthermore, the monitoring network may benefit from upgrading.

- Human and financial resources for operation and maintenance of monitoring stations are not adequate, and it is recommended that funds and resources are increased to support operation and maintenance of the air quality monitoring network. A similar observation is valid for the calibration laboratory, which does not have adequate funds and human resources for operation and maintenance and may benefit from additional support.

- It is recommended to include speciated chemical analysis on a campaign basis or at hot spots to investigate pollution sources via receptor modeling. Such chemical analyses might include but not be limited to heavy metals and major chemical constituents and species of PM, including organic carbon (OC), elemental carbon (EC), BC, ammonia (NH_3), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs). Receptor modeling can be used for further identification and quantification of air pollution sources. A source apportionment study was conducted in Skopje and MEPP staff have requisite capacity to apply Positive Matrix Factorization (PMF). It is recommended that these capacities be further developed and MEPP staff participate in EU-wide modeling and source apportionment study groups and activities. Human resources and additional funding are required for this purpose.

Chapter 2. Health Burden and Economic Cost of Ambient Air Pollution in North Macedonia

2.1 Introduction

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 (GBD) studies (that is, lung cancer, IHD, COPD, lower respiratory tract infection [LRTI], and stroke). These findings underscore the need to prioritize actions to tackle AAP.

This chapter focuses on estimation of the health burden (that is, mortality) and cost of AAP ($PM_{2.5}$), based upon available information on population exposure, background health statistics, and economic data for North Macedonia. In winter months, in addition to long-term mortality, air pollution is responsible for acute health effects, such as increases in cardiovascular and respiratory hospital stays, and lost workdays. However, these acute health effects are not estimated in this study.

2.2 Analytical Approach to Health Damage Estimation

In line with the EU strategies 'Clean Air for Europe' (CAFÉ) (CEC 2001) and 'Environment and Health for the Urban Environment', the problems of toxic emissions and their impacts on human health need to be addressed with an integrated approach. This approach includes estimation of the health burden of air pollution, valuation of attributable health burden, identification of responsible polluters, and prioritization of cost-efficient mitigating interventions. This report focuses on estimation of the cost of AAP, based on the GBD 2016 methodology, using available information on population exposure, background health statistics, and economic data. Annexes B–D of this report provide additional details on the methodology used in this chapter.

Step 1. Estimate *population exposure* to the pollutant of interest (PM with diameter less than 2.5 µm - fine particulates [$PM_{2.5}$]) in terms of number of people exposed and level(s) of concentration.

Step 2. Calculate the *health burden*, premature death (mortality) due to a disease, that may be *attributed to the pollutant* in question ('population attributable fraction' [PAF]) based on population exposure and relative risk that the pollutant presents for the occurrence of the disease, as per epidemiological studies.[1]

Step 3. Estimate the *economic value* of this health burden in monetary terms based on the welfare-based approach.

The strongest causal associations are seen between $PM_{2.5}$ pollution and cardiovascular and pulmonary diseases. Particles of smaller size reach the lower respiratory tract and thus have greater potential for causing lung and heart disease. Only health risk that is associated with mortality is assessed in this report.

This report estimates the risk of long-term mortality by age group associated with air pollution as PAFs of

1. IHD (population above 30 years of age);
2. Stroke (population above 30 years of age);
3. Lung cancer (population above 30 years of age);
4. COPD, (population above 30 years of age); and
5. LRI (all ages).

This study provides updated national estimates of mortality and associated costs compared to an earlier World Bank Green Growth study (World Bank 2014), calculated mortality and cost estimates that were about 16 percent and 60 percent lower, respectively, than the estimates provided in this report. The current study incorporates a number of updates related to improvements in air quality monitoring, exposure, and background mortality data, as well as methodological updates for health impact valuation. Specifically, in 2012 only two monitoring stations (Karpos and Centar) measured $PM_{2.5}$, both in Skopje. Since 2017, additional stations in Bitola, Kumanovo, and Tetovo have been measuring $PM_{2.5}$. Also, this study uses the GBD 2016 methodology to adjust mortality causes in the country. GBD 2016 developed an approach to define mortality causes in each country that are consistent with WHO methodologies, with comprehensive presentation of causes of death across all age groups. The GBD approach allows comparison of AAP-related health outcomes across different countries. World Bank (2014) applied the methodologies of Pope et al. (2002) and Ostro (2004) for estimating mortality and Ostro (1994) and Abbey et al. (1995) for morbidity assessment. These earlier studies were updated by the GBD project for mortality, incorporating the latest advances in epidemiology for calculating the age-specific and disease-specific impacts of pollution on mortality. Finally, this report uses an updated methodology for valuation of health impacts of air pollution, as summarized in Narain and Sall (2016). The welfare-based approach used in this study is recommended for valuation of the cost of air pollution on a national level.

A recent study by Martinez et al. (2018) estimated 1,199 premature deaths attributed to AAP for only the Skopje metropolitan area, implying a health burden that is significantly higher than estimated by both the World Bank (2014) study and this report. This discrepancy is explained by the use of a linear concentration-response function applied by Martinez et al. (2018). The same methodology is used in a recent study that

---

[1] Relative risk is defined as the ratio of the probability of a health outcome, namely premature death (mortality) or disability from a disease, occurring in an exposed group to the probability of it occurring in a non-exposed group.
PAF is defined as the reduction in population health outcome that would occur if exposure to the pollutant were reduced to an alternative ideal exposure scenario, such as pollutant concentrations below WHO limits. (Adapted from WHO definition at www.who.int/healthinfo/global_burden_disease/metrics_paf/en/ Accessed February 13, 2018).)

estimated annual mortality attributed to air pollution in all major urban areas of Macedonia (Dimovska and Gjorgjev 2018). By contrast, this report used a supralinear concentration-response function, as recommended in GBD 2010–2016, for the health outcomes examined in this study.

2.3 Ambient Air Quality and Exposed Population in North Macedonia

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, based on the North Macedonia National Air Quality report (MEPP 2017) and the work of van Donkelaar et al. (2015). To estimate exposure to $PM_{2.5}$, the share of $PM_{2.5}$ to PM_{10} was calculated as 0.6 based on the average of observations from air quality monitoring stations where both PM_{10} and $PM_{2.5}$ concentrations were measured in 2017. The $PM_{2.5}/PM_{10}$ share of 0.6 is conservative in comparison to the estimate of 0.7–0.8 provided in MEPP (2018). Table 2.1 shows the estimation of exposure in North Macedonia in different agglomerations where PM concentration is measured and in areas that reflect background concentrations.

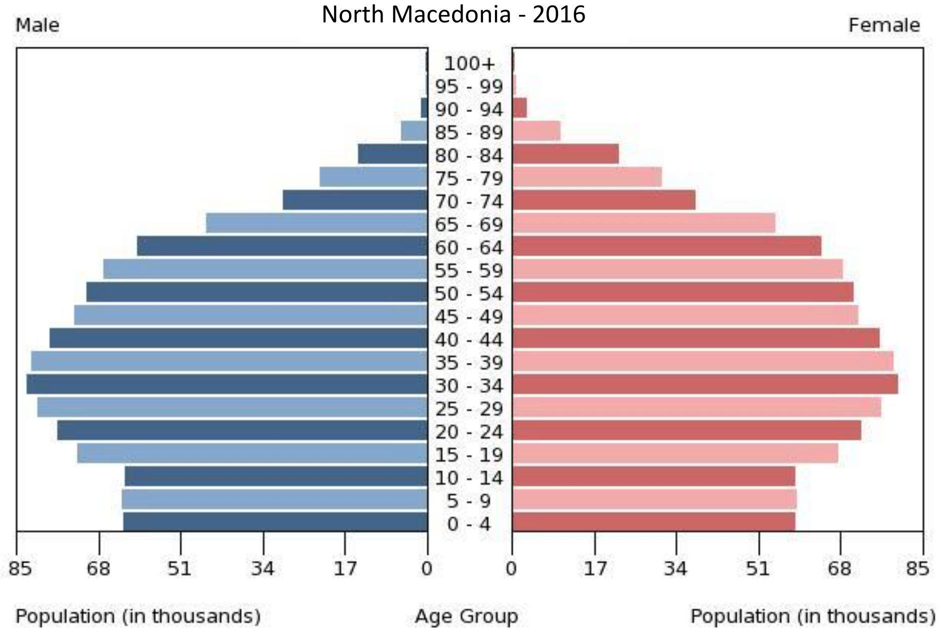
Table 0.1. Exposure to $PM_{2.5}$ pollution in North Macedonia

Agglomeration	Average annual $PM_{2.5}$ concentration, (μg/m^3)	Population in 2016 (million)	Population-weighted average annual $PM_{2.5}$ concentration, (μg/m^3)
Skopje	43	0.62	
Bitola (urban Pelagonia)	15	0.13	
Kavadartsi (urban Vadar)	25	0.09	
Kichevo (urban Southeast)	33	0.10	
Kochani (urban East)	50	0.10	
Tetovo (urban Polog)	37	0.32	
For polluted areas			37
Other (rural population)	14[a]	0.61	
For background areas			14

Source: Estimated by authors based on MEPP 2017 and van Donkelaar et al. 2015.
Note: a. Estimated based on van Donkelaar et al. 2015.

The age structure of a society is relevant to health statistics, as older people are more likely to die as a result of the pollution. Most European countries are aging rapidly. Aging of the population in North Macedonia is not quite as pronounced as in the rest of Europe. Figure 2.1 illustrates the demographic age structure of North Macedonia.

Figure 0.1. Demographic age structure of North Macedonia

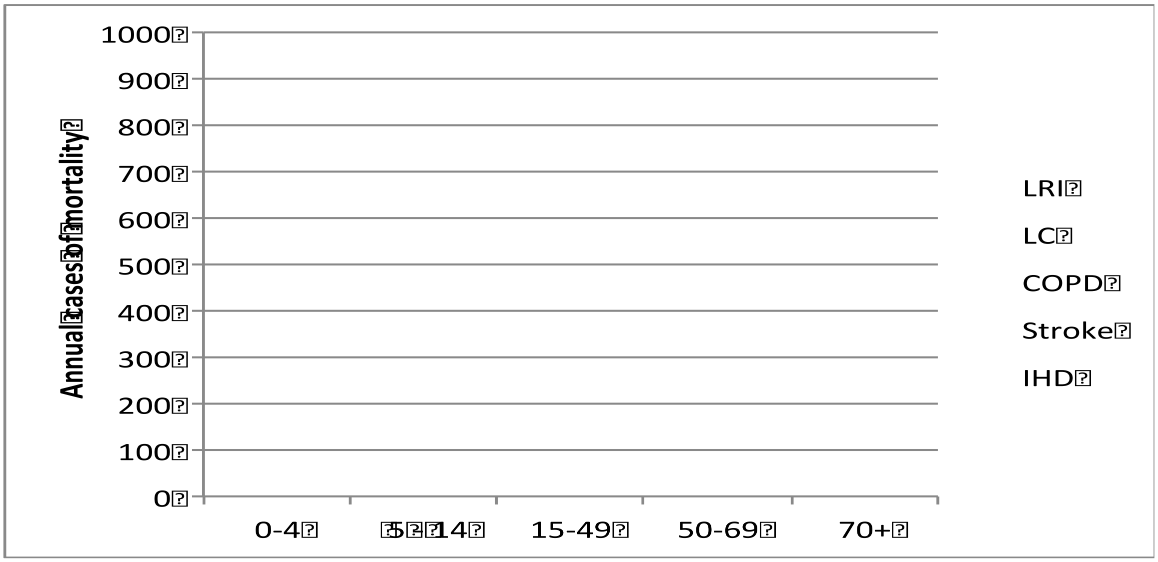


Source: World Factbook of the U.S. Central Intelligence Agency 2016.

2.4 Health Burden of Exposure to Ambient Air Pollution in North Macedonia

The estimate of the health burden attributable to AAP in North Macedonia is based on country-specific data for North Macedonia in the GBD database, which provides mortality by cause for five diseases—lung cancer, COPD, IHD, stroke, and LRI—among others. In comparison to GBD 2016, national background mortality statistics for North Macedonia are significantly lower for some diseases caused by $PM_{2.5}$, notably cardiovascular mortality, especially in the population over 45 years of age. For this reason, direct application of national background mortality statistics would underestimate $PM_{2.5}$-related mortality due to cardiovascular disease relative to GBD 2016. Using annual average exposure to $PM_{2.5}$ pollution and background mortality from GBD 2016, the total annual mortality attributed to AAP ($PM_{2.5}$) in 2016 is presented in Figure 2.2 and Table 2.2.

Figure 0.2. Estimated mortality by cause from air pollution in North Macedonia in 2016



Source: Estimated by authors from GBD 2016.
Note: LC = Lung cancer.

Table 0.2. Annual mortality attributed to AAP in North Macedonia

Age group	0–4	5–14	15–49	50–69	70+	Total
IHD	0	0	48	214	409	671
Stroke	0	0	28	157	417	602
COPD	0	0	3	31	95	128
Lung cancer	0	0	13	98	49	159
LRI	3	0	3	7	20	34
Total	3	0	94	508	989	1,595

Source: Estimated by authors.

In total about 1,600 people die from causes associated with AAP in North Macedonia every year. About 80 percent of the deaths are from cardiovascular diseases. About 61 percent of deaths from IHD and 69 percent of deaths from strokes occur in people over 70 years of age. Cardiovascular diseases mostly affect population groups older than 65 years of age. According to GBD 2016, 65 percent of cardiovascular deaths are of people ages 70 years and older. Thus, this population subgroup should be a focus of specific mitigation measures to reduce the impacts of air pollution in North Macedonia.

Based on the estimated exposure, about 21 percent of the total health burden attributed to AAP originates in Skopje.

2.5 Economic Cost of Exposure to Ambient Air Pollution in North Macedonia

In monetary terms, the economic burden associated with the health impacts of AAP is quantified using a welfare-based approach and presented in Table 2.3. The welfare-based cost of mortality is calculated by multiplying the estimated number of premature deaths by the value of statistical life (VSL). The VSL represents an aggregate of individuals' willingness to pay (WTP) for marginal reductions in their mortality risks, and thus, estimates a welfare loss of the individual associated with a statistical case of mortality. The methodology used for mortality valuation is provided in Annex C.

The annual cost of mortality caused by AAP in North Macedonia is estimated at US$500–900 million (equivalent to 5.2–8.5 percent of gross domestic product [GDP] in 2016) (Table 2.3).

Table 0.3. Annual cost of AAP in North Macedonia (US$, billions)

	Value	High	Low
Cost of pollution in urban/industrial areas	0.6	0.7	0.4
Cost of pollution in other areas	0.15	0.2	0.1
Total cost of pollution	0.75	0.9	0.5
% GDP in 2016	6.9	8.5	5.2

Source: Estimated by authors.

2.6 Conclusions

The health and economic burdens of poor ambient air quality in North Macedonia are significant. AAP caused 1,600 deaths in 2016, of which 80 percent were from IHD and stroke jointly. Population age groups over 65 years carry a significant share of the health burden. About 94 percent of this health burden is carried by people 50 years and older. The economic cost associated with the health damage from AAP in North Macedonia is on average US$750 million, equivalent to 6.9 percent of GDP in 2016. About 21 percent of the health burden attributed to AAP occurs in Skopje. The significant health and cost consequences of AAP in North Macedonia underscore the need for a concerted effort to reduce air pollution in the country.

Ultimately, air pollution is most significantly felt at the local level. Interventions to tackle air pollution should be based on understanding air quality and its deleterious health impacts at the local level. Specific recommendations by which North Macedonia could strengthen the analytical basis for informing decision making on AQM are described in the following paragraphs.

Strengthen Capacity to Conduct Health Risk Assessment

The government should strengthen institutional capacity of public health institutions to conduct routine health impact assessment from environmental risk factors, notably AAP, as well as the capacity to conduct health risk assessment to analyze health effects of industrially contaminated sites that have been identified as hot spots in the country.

Strengthen Health Statistics to Allow Estimation of AAP-Related Mortality by Cause

The government should bring health statistics in line with the needs of assessing AAP-related health risk and estimating mortality attributable to specific diseases. For health risk assessment as part of AQM, North Macedonia should make all health indicators transparent and readily accessible so that they reflect the health burden in the most polluted areas. There should be increased reporting of site-specific mortality statistics, which should reflect not only numbers for all diseases combined but also for mortality by individual disease or cause, attributable to AAP. This would enhance understanding and estimation of the health burden associated with air pollution and facilitate international comparisons which can be done using global databases such as the GBD.

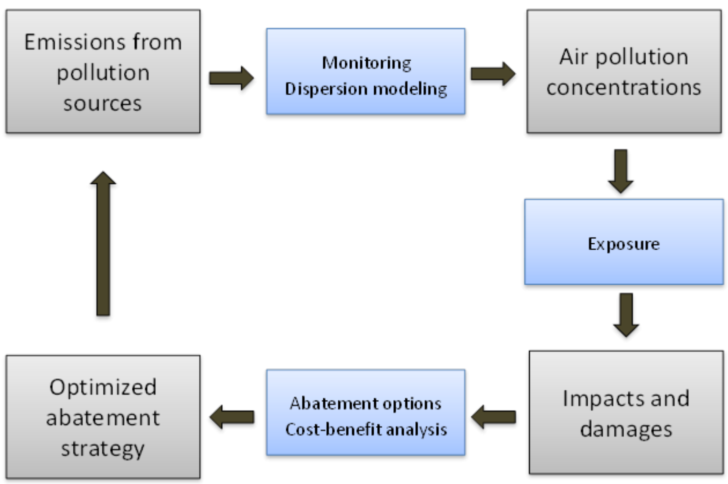
Improve Site-specific Collection and Morbidity Data Reporting Attributable to AAP for Specific Diseases, Age Groups, and Locations

The government could improve the completeness and comprehensiveness of morbidity data collected in the country and strengthen morbidity reporting related to specific diseases, age groups, and locations in the format appropriate for health risk analysis. Although some morbidity data are available in North Macedonia, notably in Skopje, a comprehensive list of morbidity health endpoints attributable to AAP should be discussed and incorporated in collection and reporting efforts more widely in the country. Timely collection and reporting of data should be promoted by the government, which as a minimum should include (a) bronchitis prevalence for children 6–12 years old, (b) chronic bronchitis including COPD incidence for adults over the age of 18, (c) cardiovascular hospital admissions, (d) respiratory hospital admissions, and (e) lost workdays. Such data should be area specific for urban or rural areas in particular where ambient air quality monitoring is in place.

Chapter 3. Key Sources of $PM_{2.5}$ Exposure3.1 Introduction

To effectively address air pollution, a comprehensive and integrated approach to AQM is needed. This approach embodies the concept of a continuous cycle of planning, implementing, evaluating, and adjusting abatement strategies and measures for continual improvements (Figure 3.1). The key elements of this approach include (a) understanding air pollution sources such as energy generation, traffic, households, industry, agriculture, and others; (b) understanding air quality; (c) understanding health impacts; and (d) optimizing abatement strategy on the most economically effective interventions. This approach should also consider existing policy and operational constraints that could foreclose or limit the implementation of certain air pollution reduction interventions.

Figure 0.1. Framework for comprehensive integrated AQM



Source: Awe et al. 2015.

This chapter addresses the following foundational pillars of the above framework:

(a) Understanding air pollution sources which involves the identification of emission sources including their geographic location, by conducting a detailed inventory and analysis of emission sources, including stationary and non-stationary (fixed and area) sources. Emission inventories are needed both at the national level and the local level where people are most exposed to air pollution and where AQM actions are taken. Emission inventories also provide a vital input for understanding the contributions of different polluting sources to ambient pollutant concentrations.

(b) Understanding ambient air quality, based on atmospheric modeling, to determine ambient concentrations of air pollutants.

North Macedonia is now regularly reporting emissions to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) with full documentation (Krsteska et al. 2018).[2] The analytical work to be presented

[2] As indicated by the MEPP, the last Stage 3 review report found the inventory to be generally in line with the 2013 EMEP/EEA Emission Inventory Guidebook and reporting requirements of the United Nations Economic Commission for Europe.

in this chapter compares model-calculated $PM_{2.5}$ concentrations with recent observations from local measurement networks to develop source apportionments for ambient $PM_{2.5}$.

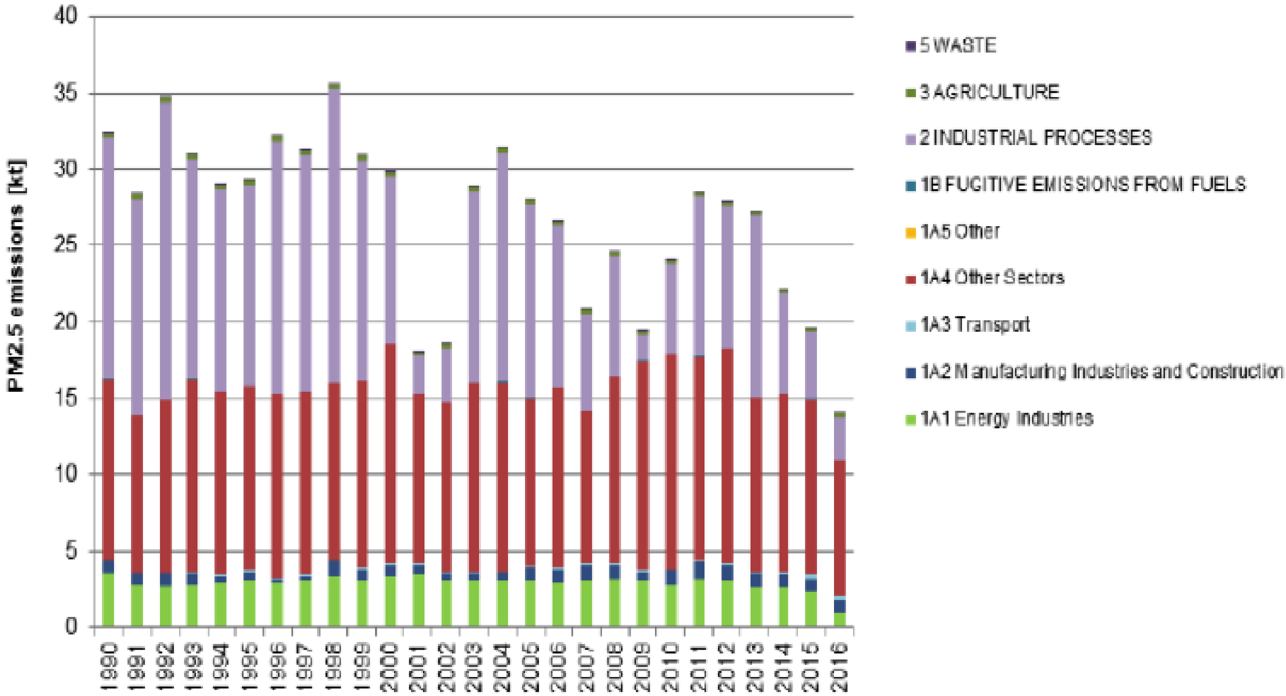
The following sections of this chapter first provide a qualitative description of AAP sources, primarily PM, in North Macedonia. This is followed by a more quantitative national-level analysis, using the GAINS model to better understand the emission source structure and key contributors to air pollution in North Macedonia, by generating modeled $PM_{2.5}$ concentrations and developing future emission scenarios and a source apportionment for populations' exposure to ambient $PM_{2.5}$. The analysis and discussion in this chapter focuses primarily on $PM_{2.5}$, the most documented pollutant for its detrimental effects on human health. Some precursors of $PM_{2.5}$ are also discussed.

3.2 Air Pollution Emission Sources and Trends in North Macedonia

According to a 2017 report of North Macedonia's MEPP, the sources of air pollution in North Macedonia are road traffic, industry and energy production, residential heating, and other sources including agriculture, waste, and construction (Figure 3.2). According to a recent emission inventory report for North Macedonia,[3] the main emission sources for PM_{10} in 2016 are residential heating with a share of 46 percent of total PM_{10} emissions, industrial processes and product use (mainly ferroalloys production) with 22 percent, and energy production 11 percent. With a share of 12 percent in 2016, the sector agriculture is also contributing to the total PM_{10} emissions. Similarly, the main emission sources for $PM_{2.5}$ in 2016 are residential heating with a share of 58 percent, industrial processes and product use (mainly ferroalloys production) with 20 percent, and energy industries with 6 percent. Fugitive emissions, agriculture, and waste are reported to be minor sources of $PM_{2.5}$ emissions in 2016.

[3] Informative Inventory Report 2018 for 1990–2016, submission under the CLRTAP.

Figure 0.2. $PM_{2.5}$ emissions by sector, 1990–2016

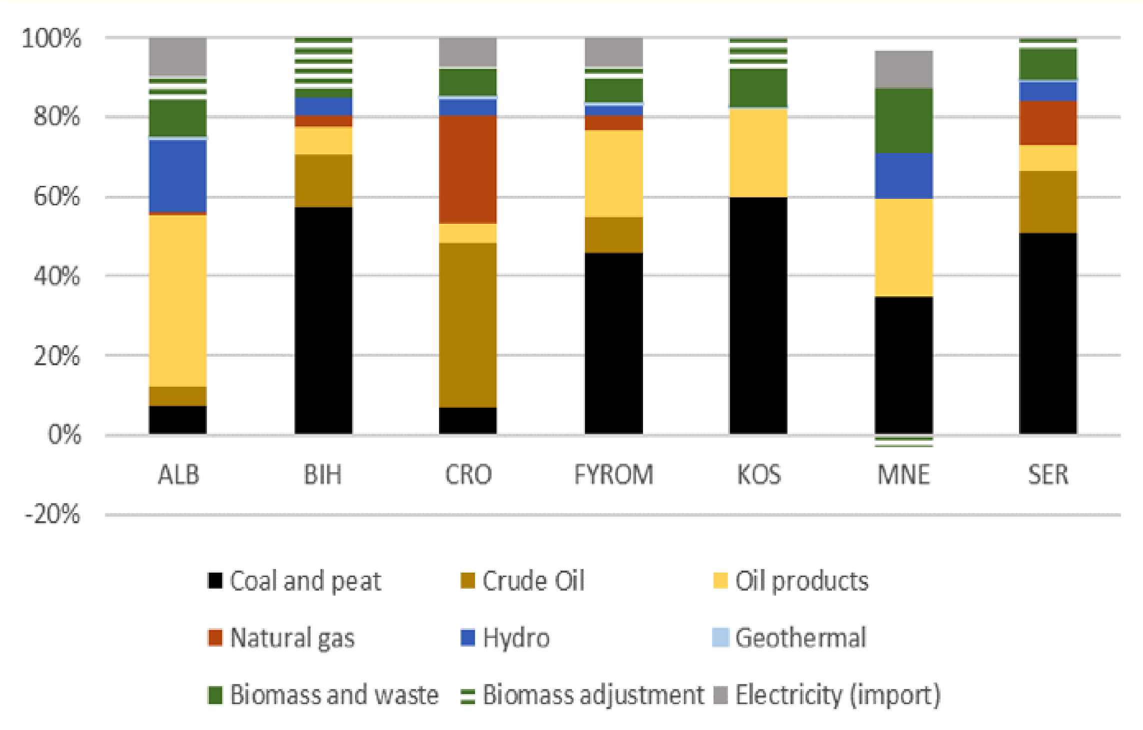


Source: MEPP 2018.
Note: Residential heating and cooking is labeled 'other sectors.'

The use of wood 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. The primary energy supply profile for North Macedonia indicates that coal and peat accounted for about 50 percent of primary energy supply in 2012, followed by oil products and biomass and waste accounting for about 20 percent each respectively (Figure 3.3) (World Bank 2017).

Industry affects air quality at the local level due to old industrial plants that do not have modern emission reduction systems (MEPP 2017). According to information provided by the MEPP, major sources include ferroalloy production facilities such as Jugohrom and power plants such as REK Bitola and REK Oslomej. Other sources include facilities for cement production, iron and steel production, and refineries. At the time of preparation of this report, some of the industrial facilities were out of operation, and others experienced temporary stops in operation due to financial problems and other causes. For example, the Jugohrom ferroalloy production facility has not been operational since 2016. Table 3.1 provides additional information about the description and status of operation of some of the major industrial facilities in North Macedonia.

Figure 0.3. Primary energy supply of West Balkan countries, adjusted for unregistered biomass consumption



Source: World Bank 2017

Note: ALB = Albania; BiH = Bosnia and Herzegovina; CRO = Croatia; FYROM= North Macedonia; KOS = Kosovo; MNE = Montenegro; SER = Serbia.

Table 0.1. Major industrial facilities in North Macedonia

Installation	Capacity (MW)	Activity	BAT	IPPC license	NERP Yes/No	Remark
001-REK Bitola	700	LCP (coal)		No	Yes	
002-REK Oslomej	120	LCP (coal)		No	Yes	Not in operation since February 19, 2018, due to regular maintenance. In the past years, it has been working only few months in the heating season due to coal deficiency.
003-ELEM AD Energetika	100	LCP (natural gas)		No	No	
004-Toplana Zapad		LCP (natural gas)	70% of capacity ultralow NO_x burners	Yes	Yes	Working during heat season October 15–April 15)
005-Toplana Istok	294	LCP (natural gas)		Yes	Yes	Working during heat season

Installation	Capacity (MW)	Activity	BAT	IPPC license	NERP Yes/No	Remark
						(October 15–April 15)
006-Rafinerija OKTA		Refinery	Desulfurization	Yes	Yes	Not operational since March 2013
007-Cementarnica USJE	120	Cement production	Yes Fabric filter	Yes	No	
008-FENI Industry	180	Ferroalloys production	Yes ESF, fabric filter, scrubber	Yes	No	Not operational since 2017 due to bankruptcy
009-Arcelor Mittal		Iron and steel production	Yes Gasification, water purification system	Yes	No	
010-Makstil AD Skopje		Iron and steel production	Yes Fabric filter Fume to stop fugitive emissions	Yes	No	
011-TE-TO AD Skopje	230	LCP (natural gas)	Yes Environmental burners for low emissions of NO_x and stable combustion mode	Yes	No	Operational for about 4 months per year (winter months) due to economic reasons
012-Jugohrom ALZAR	90	Ferroalloys production	No	Yes	No	Not operational since 2016 due to environmental inspection decision for noncompliance with the operation plan activity deadline for filter installation

Source: Information provided by the MEPP to World Bank team in June 2018.
Note: LCP = Large Combustion Plant; IPPC = Integrated Pollution Prevention and Control.

In many countries, traffic is typically a source of air pollution, notably in urban areas. In North Macedonia, air pollution from road traffic is related to factors such as high intensity of traffic and partly because of aged vehicles, which is linked to the vehicle emission control technology and inadequate vehicle maintenance. However, the foregoing statistics do not indicate transport as a major pollution source in North Macedonia. This may be related to inconsistencies associated with changes in methods for calculation of transport emissions as well as obsolescence of the database for the National Car Registry of North Macedonia. These observations signal a need for a more complete and accurate inventory of transport emissions. Furthermore, 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 and need to be better understood and addressed with appropriate control measures.

Emission Trends of Particulate Matter Pollution

North Macedonia has made notable progress in reducing air pollution, notably PM, during the past three decades as may be observed from Figure 3.2. During this period, PM emissions in North Macedonia have decreased by nearly one-third. In 1990 national total $PM_{2.5}$ emissions amounted to 32 kilotons and decreased by 57 percent in 2016 to 14 kilotons. Similarly, national PM_{10} emissions have decreased by 59 percent, from 48 kilotons in 1990 to 19.62 kilotons in 2016. These decreases are associated with decreases in industrial emissions due mainly to closures and limited operating hours in ferroalloy facilities, which have also had a secondary effect of reducing electricity demand. At the same time there have been significant reductions in emissions from residential heating (labeled 'other sectors'), fueled mainly by solid biomass. The decrease of about 25 percent in residential PM emissions from 2015 to 2016 is attributed to a reduction in biomass use and an apparent increase in the use of gaseous fuels (MEPP 2018).

3.3 Analysis of Sources of $PM_{2.5}$ Exposure and Ambient Concentrations of $PM_{2.5}$

GAINS methodology. The development of any AQM plan, including economically effective interventions to address air pollution, requires a firm understanding of the contributions of various economic activities to ambient air quality. This study produced a national-level source apportionment that estimates the current contributions of key sectors (for example, power plants and industry, transport, residential combustion, agriculture) to ambient $PM_{2.5}$ concentrations. It is important to note that this analysis provides a national-level source apportionment and that additional analysis would be required to better understand source apportionment at the local level, including in hot spots.

The quantitative analyses in this chapter were performed with the GAINS model developed by the International Institute for Applied Systems Analysis (Box 3.1) (Amann et al. 2011). GAINS is used as part of the standard modelling framework for negotiations under the CLRTAP and the EU.[4]

GAINS uses linear source-receptor coefficients to calculate ambient $PM_{2.5}$ concentrations from emissions of $PM_{2.5}$ and precursor gases (SO_2, NO_x, NH_3, and non-methane volatile organic compounds [NMVOC]). These source-receptor coefficients are derived from full-year perturbation simulations of the European Monitoring and Evaluation Program (EMEP) Chemical Transport Model (Simpson et al. 2012), in which emissions from one source country and one pollutant are reduced by a given percentage. The response in simulated ambient concentrations is then used to define source-receptor coefficients from countries to grid concentrations at approximately 28 km resolution (0.5° × 0.25°). For primary PM emissions from low-level sources (residential combustion and traffic), a downscaling is applied to 7 km resolution (0.125° × 0.0625°) to reflect small-scale concentration gradients. For details see Kiesewetter et al. (2015a, 2015b).

To estimate contributions from individual source sectors to ambient $PM_{2.5}$, bottom-up calculated emissions from individual sectors are multiplied with the appropriate pollutant-specific transfer coefficients and then summed across pollutants. Population exposure is calculated from the overlay with gridded population (Gallego 2010) at the same resolution.

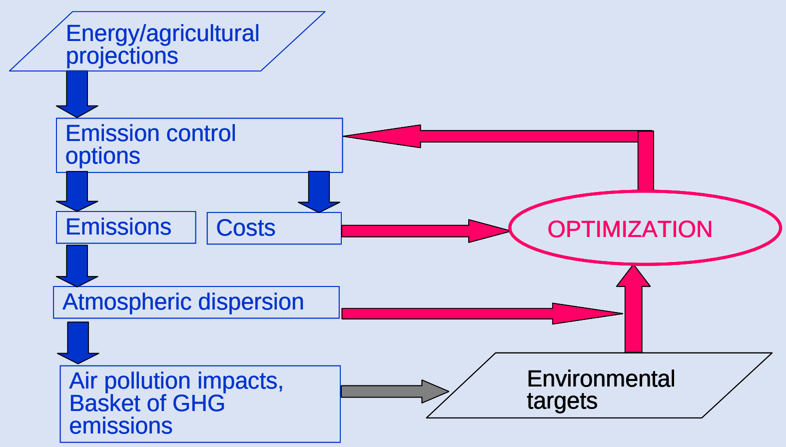
[4] http://www.iiasa.ac.at/web/home/research/researchPrograms/air/GAINS.html.

In this report, the GAINS model is used to: (a) estimate baseline and future emission scenarios of $PM_{2.5}$, $PM_{2.5}$ precursor emissions (SO_2, NO_x, NMVOC, and NH_3), and BC up to 2030; (b) estimate ambient $PM_{2.5}$ concentrations at the spatial resolution of 7 × 7 km, with the sectoral emission estimates of the GAINS model, computations of the EMEP atmospheric chemistry transport model of the long-range dispersion of pollutants, and local information on the distribution of low-level emission sources, meteorology, and topography (Kiesewetter et al. 2015b); and (c) extract the contributions made by each individual emission source to ambient $PM_{2.5}$ concentrations at a given receptor site based on the model calculations.

Box 0.1. The GAINS Model

The GAINS (Greenhouse Gas-Air Pollution Interactions and Synergies) model explores cost-effective multipollutant emission control strategies that meet environmental objectives on air quality impacts (on human health and ecosystems) and greenhouse gases. GAINS brings together data on economic development (including energy and agricultural projections that typically originate from external supply-demand models); the structure, control potential, and costs of emission sources; the formation and dispersion of pollutants in the atmosphere; and an assessment of environmental impacts of pollution. The model allows simulation of the impacts of policy actions that influence future driving forces (for example, energy consumption, transport demand, agricultural activities), dedicated measures to reduce the release of emissions to the atmosphere, on total emissions, resulting air quality, and a basket of air quality and climate impact indicators. GAINS addresses air pollution impacts on human health from fine PM and ground-level O_3, vegetation damage caused by ground-level O_3 the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions.

GAINS assesses, for each of the source regions considered in the model, more than 1,000 measures to control emissions to the atmosphere. It computes the atmospheric dispersion of pollutants and analyzes the costs and environmental impacts of pollution control strategies. In its optimization mode, GAINS identifies the least-cost balance of emission control measures across pollutants, economic sectors, and countries that meet user-specified air quality and climate targets. The flow of information in the cost-effectiveness analysis of the GAINS model is illustrated below:



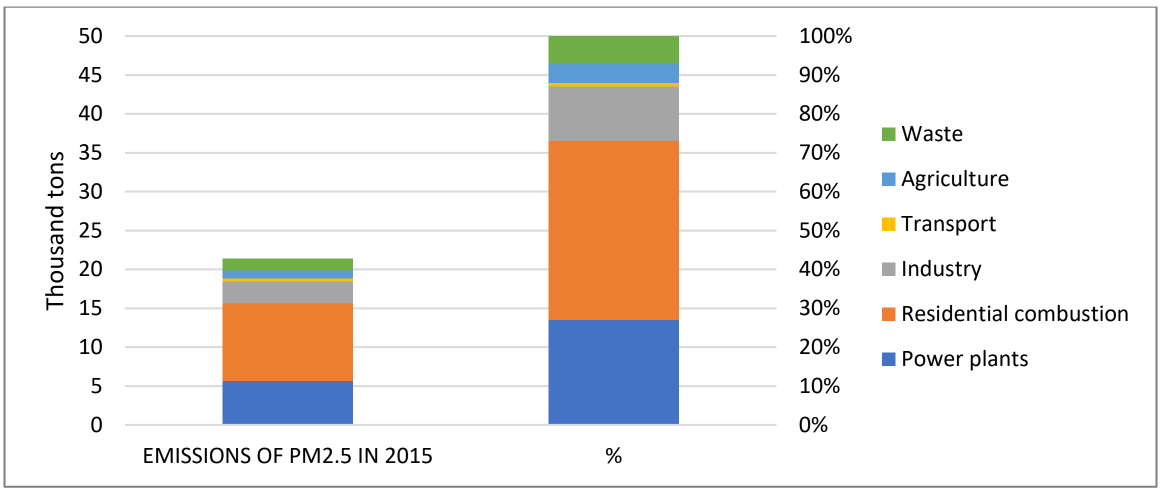
An essential element of the GAINS calculation is reliable information about activity statistics on fuel use, industrial production, fleet composition and distance travelled, and livestock numbers. GAINS draws on international and national statistical data on energy use, which provide information for fossil fuel use and key economic sectors. However, in many countries, as is the case in North Macedonia, data for the residential sector, and especially for household heating devices, are often of poor quality or suffer large uncertainties. This includes information about the use of non-commercial biomass (wood logs), low quality coal, and municipal waste, for which the real amounts are often unknown and/or not well reflected in national statistics. In addition, official statistical data often do not include information about the structure of fuel use in the residential sector, for example, allocated to heating stoves, manual boilers, automatic boilers, pellet stoves.

Updated fuel use data by combustion technology were then used in the GAINS model to calculate emissions of primary $PM_{2.5}$, particulate BC, and PM precursor emissions (SO_2, NO_x, NMVOC, and NH_3). The resulting emission estimates were compared with available national inventories submitted to the CLRTAP.

3.4 Annual Emissions Estimates in North Macedonia in 2015

Modeled $PM_{2.5}$ emissions at the national level are illustrated in Figure 3.4 and show relatively good agreement with the national inventory, both in total amount and by sectoral contributions. In 2015, total $PM_{2.5}$ emissions in North Macedonia are estimated by GAINS to be about 21 kilotons, with residential combustion contributing 48 percent and power and heating plants contributing 26 percent. Coal is responsible for more than 50 percent of the emissions of $PM_{2.5}$ from power plants, industry and residential combustion; and biomass is responsible for the remaining residential $PM_{2.5}$ emissions. It is important to note, however, that some uncertainties exist with respect to data (fuel use) and understanding of the structure and state of small combustion devices used in the residential sector.

Figure 0.4. Annual emissions of $PM_{2.5}$ in North Macedonia in 2015



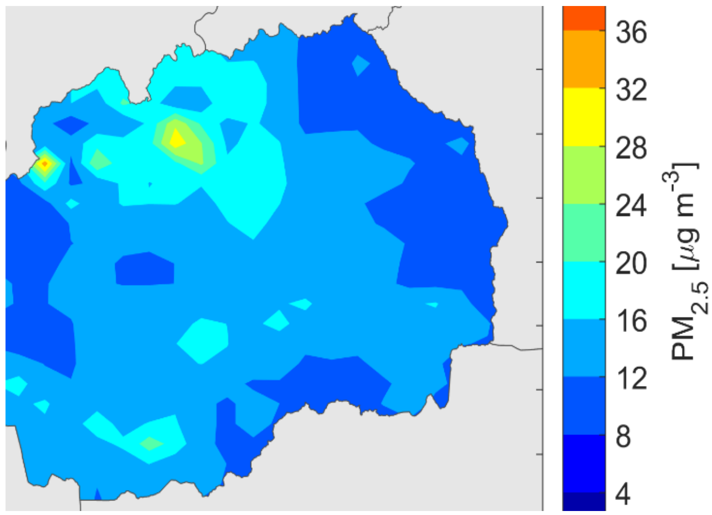
Source: GAINS Model 2018.

3.5 Ambient Concentrations of $PM_{2.5}$

As indicated previously, for this study, the GAINS model performs a national-level source apportionment. Understanding concentrations and sources at the local level will require further analysis, which is not conducted within the scope of this study. As a starting point for the source apportionment conducted in this study, the analysis computed the spatial patterns of ambient concentrations of $PM_{2.5}$ in North Macedonia for the baseline year 2015 (Figure 3.5) and compared them with available monitoring data. The highest concentrations were noted in the northwestern parts of the country, where clusters of industrial complexes are located.

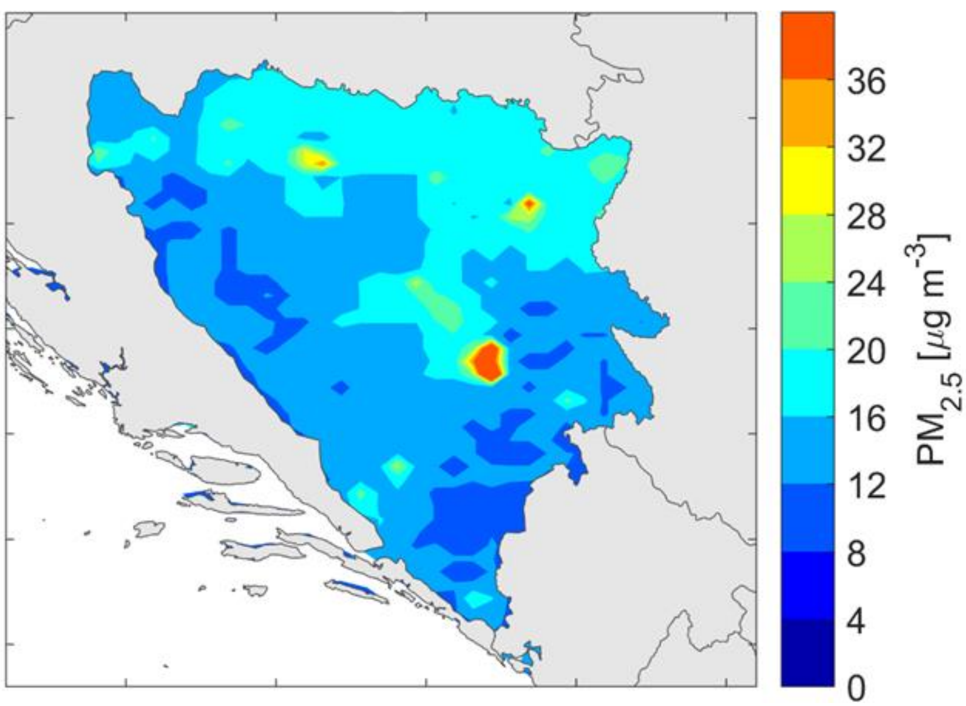
While the model calculation produces complete spatial coverage for the region, there is only a limited set of monitoring stations with sufficient temporal data coverage available against which the model results of annual mean $PM_{2.5}$ concentrations can be meaningfully compared. While observational data for North Macedonia could not be compared to the model results, suitable information was available for another Western Balkan country, Bosnia and Herzegovina. Observational data from Bosnia and Herzegovina stations with a temporal coverage of at least 75 percent for 2017 (Figure 3.7) were found to be in reasonable agreement with the GAINS estimate (Figure 3.6), especially keeping in mind the large variability within urban areas, and thus provide reasonable basis for subsequent source apportionment and scenario analyses.

Figure 0.5. Annual average $PM_{2.5}$ concentrations estimated for 2015 in North Macedonia



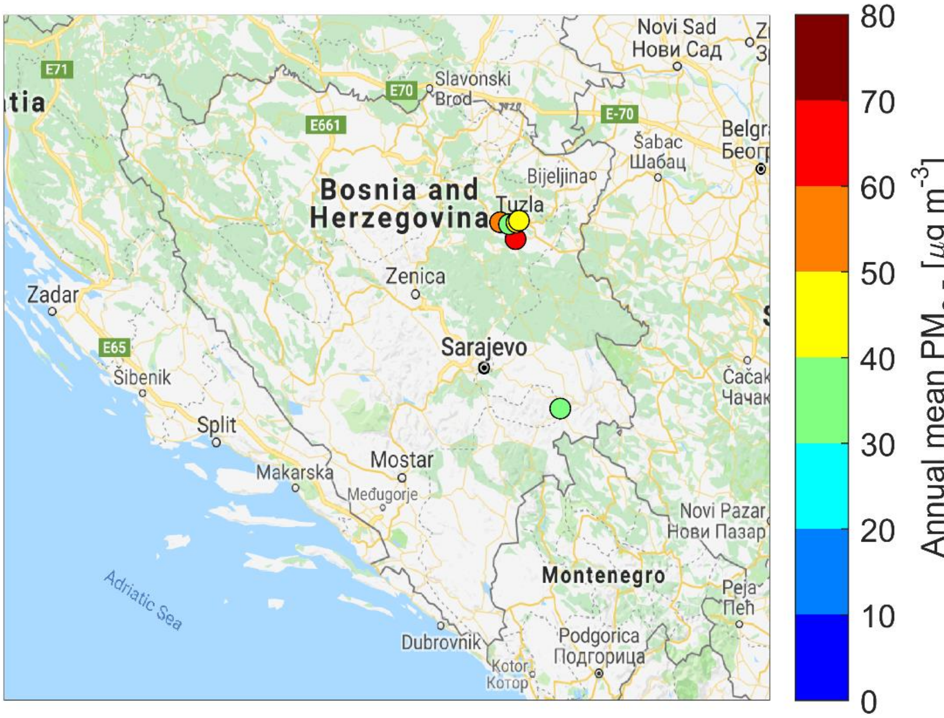
Source: GAINS Model 2018.

Figure 0.6. Annual average $PM_{2.5}$ concentrations estimated for 2015 in Bosnia and Herzegovina



Source: GAINS Model 2018.

Figure 0.7. Annual average $PM_{2.5}$ concentrations in 2017 for available stations in Bosnia and Herzegovina



Source: National Measurement Network.

3.6 Source Apportionment for Population Exposure to $PM_{2.5}$

The model calculations deliver estimates of concentrations of $PM_{2.5}$ in ambient air across the full model domain. By contrast, monitoring data are restricted to a few places of interest, often to locations of high population densities (urban areas) or with high pollution levels (for example, industrial areas). Although there may be overlaps between the full model domain and monitoring locations, the spatial distribution of population is not always identical to the distribution of pollution. Model results, combined with population data, can be used to compute the overall population exposure, which then provides important input for the development of economically effective policy interventions to reduce the harmful impacts of pollution. It is important to note, however, that strategies targeted at improvements in total population exposure could be different from priority actions to alleviate concentrations in the most polluted locations.

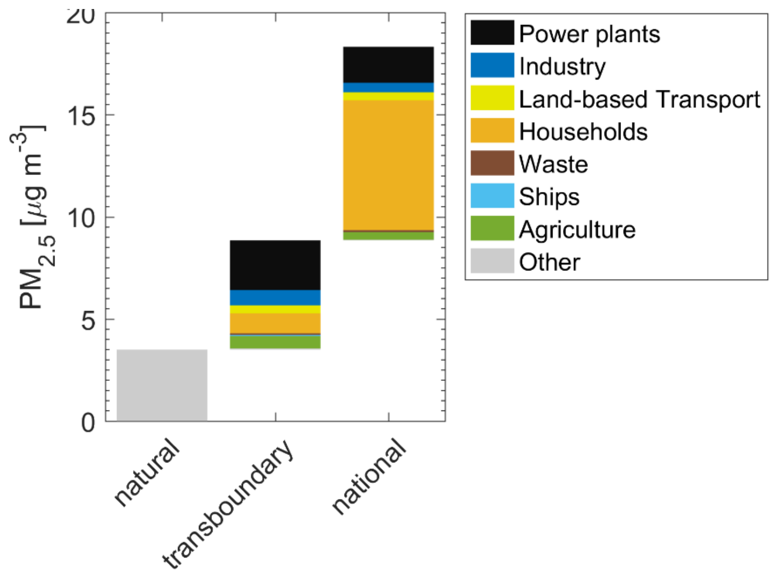
This national-level study provides model-based source apportionment analyses for population exposure, which integrate over the total population, both within the cities and in rural areas. Further analysis with more detailed information would be required to conduct reliable source apportionments at the local level, including for specific cities and locations.

Results of the source apportionment from the GAINS model show the following three notable features (Figure 3.8). The 'natural' contribution refers to natural sources such as soil, dust, forest fires, and sea salt.

- First, while there are pollution hot spots in all areas, even the population-weighted mean exposure to $PM_{2.5}$ exceeds the WHO guideline value for $PM_{2.5}$ by a factor of about 2.

- The dominant share (about 50 percent) of $PM_{2.5}$ pollution originates from within the country, and about 30 percent is imported from the neighboring countries. This is different from other countries in Europe, where the transboundary component causes the largest share (Kiesewetter and Amann 2014).
- Third, the residential sector is by far the largest source for population-weighted $PM_{2.5}$ exposure.

Figure 0.8. National-level source apportionment for population-weighted annual mean concentrations of $PM_{2.5}$ in North Macedonia for 2015



Source: GAINS Model 2018.

3.7 Future Emission Trends

Emission Scenarios

To explore the likely future evolution of emissions, air quality, and population exposure to $PM_{2.5}$ in the region, as well as the scope for improvements through dedicated policy interventions, two emission scenarios have been developed. Both scenarios use the same assumptions about the future economic development and the evolution of pollution-generating activities up to 2030. Future levels of energy use, industrial production, transport and agricultural activities are based on the macroeconomic and energy projections of the World Energy Outlook 2017 developed by the International Energy Agency, and on the projections developed for the European Commission with the PRIMES energy model and the Common Agricultural Policy Regional Impact Analysis (CAPRI) agricultural model.

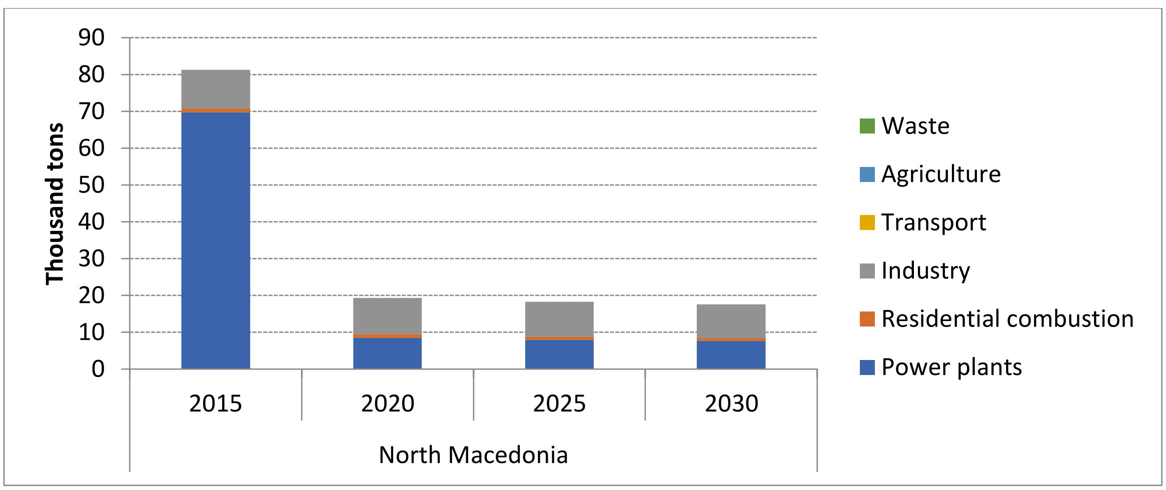
- The **baseline case** illustrates the likely development of emissions and air quality assuming compliance with the current environmental laws, considering both national and international legislation that is applicable to the countries. The key laws significantly affecting the trajectory of future emissions include the provisions of the Energy Community Treaty (Energy Community 2005), which requires compliance with the EU Large Combustion Plant Directive (EC 2001) by 2018, and the legislation for the transport sector, which the model assumes will be introduced with a 10-year delay in comparison with the EU member states.

- The **maximum technically feasible reductions (MTFR) or maximum mitigation case** outlines the scope for emission reductions that could be achieved through immediate and full application of the best available technologies for all new equipment (to the technically feasible extent), as characterized in the GAINS model. However, this case does not consider the potential from changes in energy, agricultural, and transport policies, which would affect future levels of polluting activities.

Emissions in Baseline Case Scenario

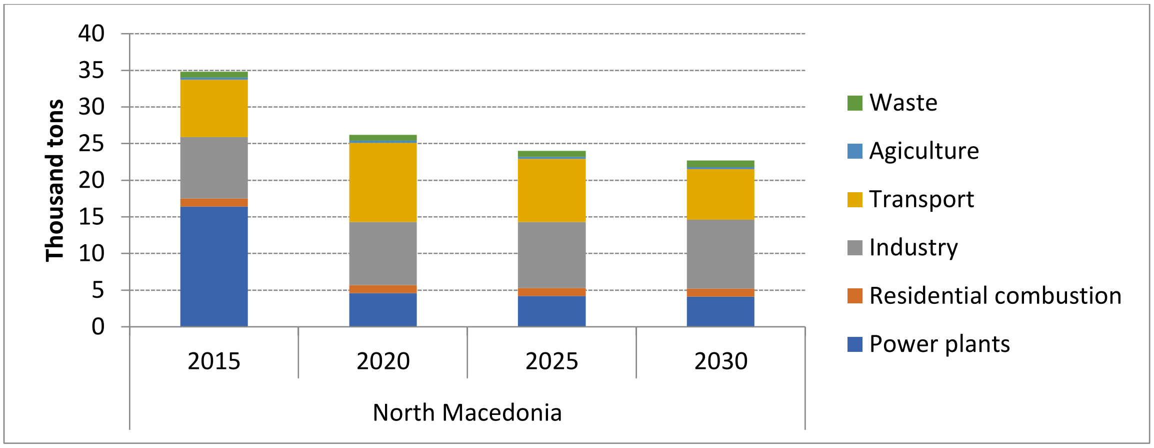
The emission trajectories for air pollutants, in the baseline scenario, are presented in the following figures. Existing environmental and air quality policies, if effectively enforced, are expected to deliver a strong decline in the emissions of SO_2 and NO_x (Figures 3.9 and 3.10), mainly due to EU legislation for large combustion plants and the emission standards for new vehicles. SO_2 emissions in the power sector will be cut by 80 percent, and NO_x emissions by up to 50 percent. At the same time, emissions of primary $PM_{2.5}$ are not likely to significantly change in the near term (Figure 3.11), as the underlying energy projections do not foresee major shifts away from fuelwood combustion in household stoves and boilers. Emissions of BC, NMVOC, and NH_3 are expected to remain at about the same level or could even increase (presented in Annex E).

Figure 0.9. Emissions of SO_2 in the baseline scenario



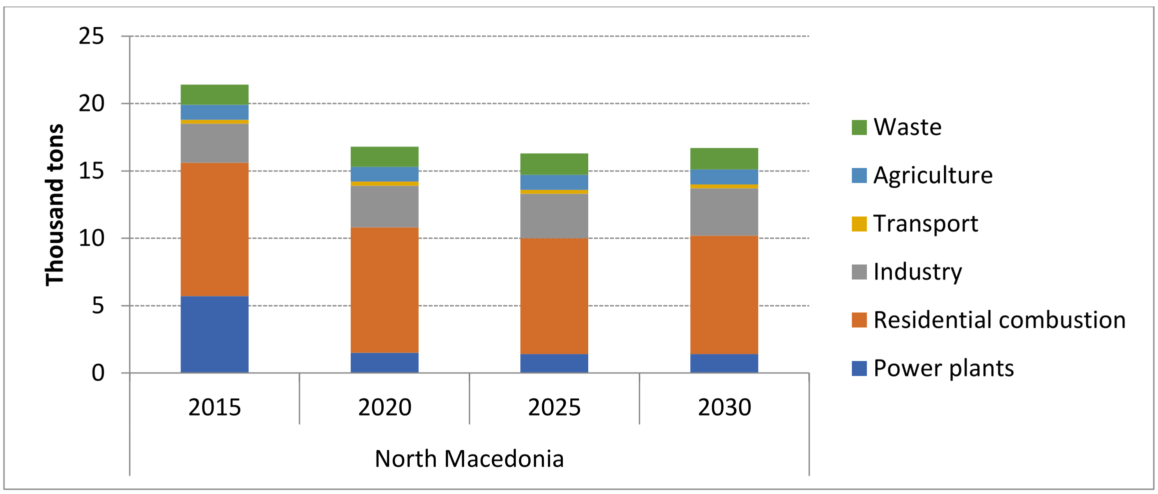
Source: GAINS Model 2018.

Figure 0.10. Emissions of NO_x in the baseline scenario



Source: GAINS Model 2018.

Figure 0.11. Emissions of $PM_{2.5}$ in the baseline scenario

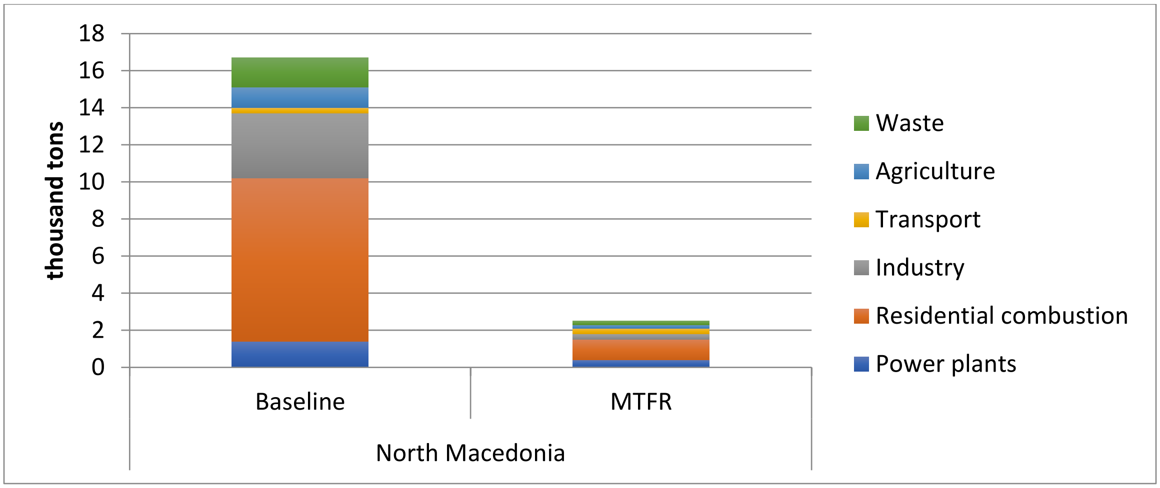


Source: GAINS Model 2018.

Emissions in Maximum Mitigation Case Scenario

For $PM_{2.5}$, the largest mitigation potential emerges in the residential combustion sector and in the industry (Figure 3.12). Since these sectors make the largest contributions currently, the overall emission reduction potential for $PM_{2.5}$ is about 90 percent and similar for BC (Annex E). The measures that would lead to such emission reductions include, among others, (a) immediate compliance of all new household stoves and boilers burning fuelwood with the stringent standards of the Ecodesign Directive of the EU, (b) replacement of the oldest existing installations, (c) assurance of adequate quality of fuelwood (fuelwood shall be dry when burned) which implies proper storage of the wood, and (d) compliance of all new industrial installations with the EU Industrial Emissions Directive . In the absence of strong financial and governance mechanisms, such in-depth changes are unlikely to occur in the near future under the assumed projections of socioeconomic development, that is, population and economic growth.

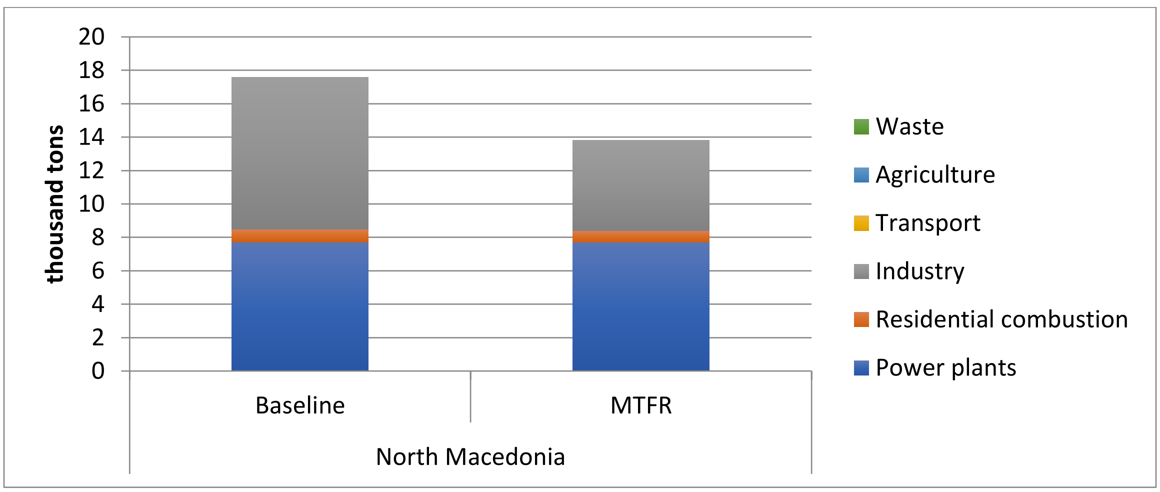
Figure 0.12. Emissions of $PM_{2.5}$ in 2030 for the baseline and MTFR scenarios



Source: GAINS Model 2018.

For SO_2, power plants and industrial emission contribute the dominating shares to national emissions. Owing to the commitments that are part of the Energy Community Treaty of which North Macedonia is a member, emissions from the power sector are expected to decline sharply by 2030 in the baseline (Figure 3.13), which leaves the largest further mitigation potential to the industrial sector (Figure 3.13).

Figure 0.13. Emissions of SO_2 in 2030 for the baseline and MTFR scenarios



Source: GAINS Model 2018.

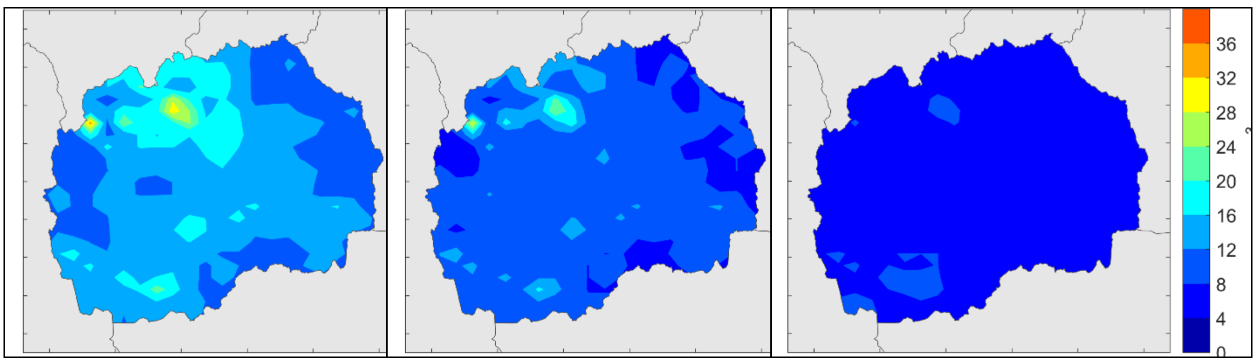
For BC and NMVOC, the largest reduction potentials beyond current legislation emerge in the residential sector (Annex E). In addition, solvent use (under industry) offers important opportunities for NMVOC reductions (for example, low solvent products or end-of-pipe measures such as incineration or recovery, which are widely applied within the EU).

NO_x emissions (Annex E) can be reduced by about 50 percent compared to the baseline in 2030 through best available technology standards involving, for example, selective catalytic or non-catalytic reduction in the power and industrial sectors, and EURO 6 equivalent standards for vehicles. For NH_3, mitigation opportunities are typically smaller since there is no technology to remove NH_3 efficiently at a large scale. Instead, reducing input of nitrogen into the system and optimizing the use of nitrogen-rich manures can avoid losses to the atmosphere and typically reduce emissions by 20–40 percent depending on the structure of emission sources (for example, the importance of urea-based fertilizer application and share of cattle in total livestock).

3.8 Future Ambient Particulate Matter Concentrations

The envisaged future emissions discussed in the above section will have significant impact on future air quality in the region. Currently, for most areas in North Macedonia, the estimated levels of $PM_{2.5}$ concentrations are significantly above the WHO guideline value of 10 µg/m^3, with urban areas exceeding this value by up to a factor of 3 (Figure 3.14). In the baseline scenario, despite the overall emission reductions, concentrations will remain high in the more densely populated areas, again because of the persistence of firewood use for heating purposes. In contrast, it would be technically feasible through measures for the residential combustion sector to bring most of the area, including many cities, below the $PM_{2.5}$ guideline value, although full implementation of all measures may be challenging.

Figure 0.14. Ambient $PM_{2.5}$ concentrations in North Macedonia in 2015 (left panel), for the baseline scenario in 2030 (center panel) and the MTFR scenario in 2030 (right panel)



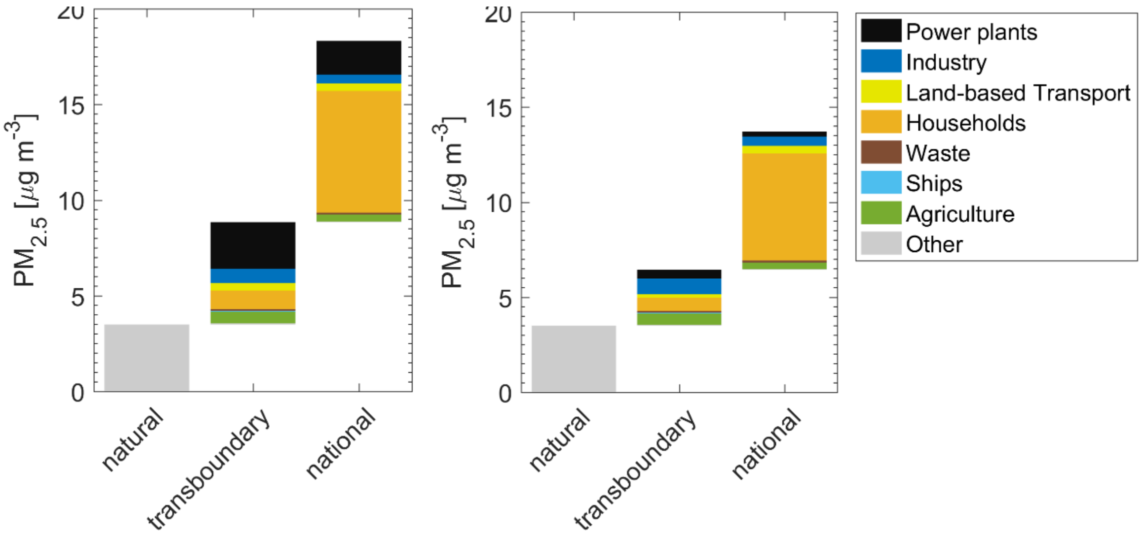
Source: GAINS Model 2018.

3.9 Future Source Apportionment

The expected declines in the emissions of the various sectors will not only have important impact on ambient $PM_{2.5}$ levels in the region but will also change the relevance of the remaining emission sources. In the baseline scenario, the emissions contributions from the power sector are strongly declining. By contrast, there will be only little changes in the emissions contributions of the residential sector, leaving considerable potential for further emission reductions by 2030.

Currently the domestic sector makes a large contribution to population exposure to $PM_{2.5}$ in North Macedonia, but the impact of other sectors, in particular power generation, is also considerable (Figure 3.15). About 50 percent of the total population exposure to $PM_{2.5}$ originates from sources within the country. By 2030, current measures for large sources, if effectively implemented, will sharply reduce their impact on population exposure, both from within the country and from the inflow from neighboring countries. In the absence of dedicated policies, the contributions from the domestic sector will persist, so that overall population exposure is expected to decline by about 25 percent. At the same time, the potential for elimination of emissions from residential combustion sources will be still untapped in 2030. From a technical perspective, measures for this sector could reduce exposure significantly compared to current levels. However, hot spots exist and will remain in the baseline case in 2030. Most importantly, further measures to approach the WHO guideline must address emissions from the residential sector.

Figure 0.15. National-level source apportionment of population-weighted mean $PM_{2.5}$ concentrations in the North Macedonia in 2015 (left panel) and for the baseline scenario in 2030 (right panel)



Source: GAINS Model 2018.

3.10 Conclusions and Recommendations

Summary of Conclusions

Several areas in North Macedonia suffer from poor air quality, with concentrations significantly exceeding the global air quality guideline for $PM_{2.5}$ established by the WHO and the air quality limit values for PM_{10} and $PM_{2.5}$ of the EU. Especially in winter, urban areas face severe smog episodes, caused by the increased demand for heat from the residential and commercial sector, which is mainly covered by fuelwood.

As the first national-level study analysing the emission source structure of $PM_{2.5}$ precursor emissions in this region (Western Balkans) in a harmonized way, the study compares modelled $PM_{2.5}$ concentrations with recent observations from local measurement networks and develops source apportionments for ambient $PM_{2.5}$ for all considered countries. It explores the future trends in emissions and air quality and identifies measures that could effectively improve the situation.

Benefiting from the North Macedonia submission of nationwide emission inventories to the CLRTAP, source apportionments have been developed that quantify the contributions of key sectors to ambient $PM_{2.5}$ concentrations. The results show that (a) the population-weighted mean exposures to $PM_{2.5}$ exceed the WHO guideline value for $PM_{2.5}$ by a factor of about 2; (b) most $PM_{2.5}$ pollution originates from within the country and not from other countries; and (c) the residential sector is by far the largest source for population-weighted $PM_{2.5}$ exposure in the country.

If effectively enforced, existing environmental and air quality policies are expected to deliver a strong decline in the emissions of SO_2 and NO_x but will not have major impacts on primary $PM_{2.5}$ emissions, as the current energy projections do not foresee major shifts away from fuelwood combustion in household stoves and boilers. While these policies should lower concentrations in large parts of the country to levels close to the WHO guideline value, concentrations in urban areas will remain high and exceed the guideline value, and in hot spots may exceed the guidelines by up to a factor of 3, mainly due to the persistence of firewood for heating purposes.

The expected declines in baseline emissions of the various sectors will not only have important impact on ambient $PM_{2.5}$ levels in the region but will also change the relevance of the remaining emission sources to population-weighted exposure to $PM_{2.5}$. Since the contributions from the power sector will decline markedly, the residential sector will remain the dominant PM emission source.

While it would be technically feasible through measures in the residential sector to bring ambient $PM_{2.5}$ concentrations in most of the country, including cities below or slightly above the $PM_{2.5}$ guideline value, full implementation of all measures will be challenging. Relevant measures would require (a) immediate compliance of all new household stoves and boilers burning fuelwood with the stringent standards of the Ecodesign Directive of the EU, (b) replacement of the oldest existing installations, and (c) assurance of adequate quality of fuelwood, which includes burning of only dry fuelwood and proper storage of fuelwood. Such changes would require strong financial and governance mechanisms for their realization.

Key Recommendations

Based on the analysis of the national emission inventories, current and potential future ambient $PM_{2.5}$ concentrations, and source apportionments, the following recommendations emerge for improving AQM in North Macedonia.

Upgrade emissions inventory activities to include more pollutants and apply more advanced emission inventory techniques. There is a need to upgrade the emission inventory activities, in particular to validate consistency of transport data used in the inventory, cover all pollutants, including BC, and further advance on using Tier 2 methods for key sources to capture the local peculiarities and technical features of the most important emission sources, and to reveal the potentials for emission reductions.

Strengthen temporal coverage of air quality monitoring. Due to the serious impacts of winter pollution episodes on air quality, attention should be given to improving the air quality monitoring system to achieve acceptable temporal coverage and quality control of air quality monitoring, with special emphasis on the winter period and areas with high population exposure to pollution.

Fill information and data gaps on fuelwood use and technology of combustion devices. Given the impact of fuelwood combustion on air quality in the country, there is an urgent need to (a) improve statistical information on the use of fuelwood in the country, including from non-commercial sources; (b) analyze the typical quality of the fuelwood used in the country; (c) assess the types of stoves and boilers used in the country and the options to reduce emissions from improved use practices; and (d) inform the households on low-emission operation of fuelwood stoves and boilers, following similar awareness campaigns in other countries.

Strengthen incentives and legislation to address emissions from household sector. It is essential that North Macedonia enforces full compliance with its current emission control legislation for stationary and mobile sources. To harness the potential for further emission reductions in the residential sector, the country could (a) put in place financial incentives and mechanisms to accelerate the replacement of old stoves and boilers and (b) expedite adoption of the ecodesign standards of the EU for small combustion devices in the household sector.

Promote regional coordination on transboundary air quality issues. The analysis in this report shows that while the dominant share (about 50 percent) of $PM_{2.5}$ pollution originates within the country, there is also an important share (about 30 percent) imported from neighboring countries. To maximize the synergies between similar or shared problems, the Government of North Macedonia could consider setting up, together with neighboring Balkan countries, a Balkan Knowledge Platform on transboundary air pollution. The knowledge platform could begin with coordination and knowledge sharing on technical aspects related to transboundary air pollution and gradually broaden the scope to collaboration on measures to address transboundary pollution based on experience and knowledge gained through interaction on the platform.

Chapter 4. Air Quality Management Institutions

4.1 Introduction

North Macedonia's institutional and policy framework for AQM has evolved rapidly over the last decades, largely driven by efforts to gradually transpose EU directives into domestic legislation. During these years, the Government of North Macedonia has developed some of the basic pillars of AQM, which are required for tackling the harmful levels of AAP observed in the country.

The Law on Ambient Air Quality (LAAQ) was adopted in 2004 and constitutes the backbone of North Macedonia's legal framework for AQM. The LAAQ gives environmental and health authorities the shared responsibility for setting limits and values for ambient air quality and emissions from stationary and mobile sources and mandates the environmental authority to prepare an annual assessment of air quality, based on the air quality data collected through national and local monitoring networks, and through emissions measurements of mobile and stationary sources. The law also contemplates instruments for air quality planning.

Over the last decades, the government has also established environmental organizations with responsibilities for AQM and assigned relevant responsibilities to authorities from other sectors. The MEPP is the country's formal environmental authority responsible for developing environmental policies, including managing all types of pollution, and monitoring environmental quality. The Macedonian Environmental Information Center (MEIC) is in charge of ambient air quality monitoring, analysis, and reporting. There is a need for sustained political commitment to achieve continued reductions in air pollution along with significantly higher resources, and capacity building at different levels.

Despite important efforts to create and strengthen the institutional and policy framework for AQM in North Macedonia, significant challenges remain in terms of bringing down AAP levels. People living in North Macedonia are typically breathing more toxic particulate air pollution than their neighbors in Western Europe. Air pollution has reached health threatening levels in most urban locations across North Macedonia, especially in Skopje, Tetovo, and Bitola, particularly during winter months (FMI and MEPP 2017). Alarmingly high levels of air pollutants prompted the government to announce a series of emergency measures in the winter of 2017–2018, including banning heavy vehicles from entering the city center.

The EU accession process is a key driver for improvements of AQM in North Macedonia. While the legislative alignment is almost complete, gaps exist, and implementation remains weak. Progress has been made in reporting air quality data and real time monitoring, but air quality improvement plans have still not been developed for all zones where the levels of pollutants exceed the limit values. The national air quality monitoring network requires considerable human, technical, and financial reinforcement. Some positive trends include a decreasing energy intensity of the economy and growing share of renewables in total electricity consumption.

In the absence of targeted interventions, AAP, specifically $PM_{2.5}$, could become even more severe, as a result of trends in industry and energy generation, domestic heating and cooking, and growing motorization. Actions are needed on multiple levels and as part of a wider strategic plan that should be based on sound data, technical inputs, and financial backing so that meaningful progress on air quality improvements can be achieved and sustained.

In the short term, North Macedonia should

- Strengthen and revise its legal framework on AQM, focusing on closing gaps in transposing the most recent European legislation and reducing pollution from domestic heating, stationary sources, and mobile sources;
- Employ economic instruments, where applicable, to move existing markets and policies toward improved environmental outcomes and better AQM;
- Improve institutional capacity to design, implement, and enforce AQM policies and existing air pollution limits through adequate staffing and resources; and
- Ensure adequate resources for institutions responsible for maintaining and utilizing the existing AQM network and laboratory.

This chapter provides an overview of the current state of North Macedonia's AQM institutions and policies at the national level. It does not provide an exhaustive institutional and policy assessment. While the merits of such assessment are recognized, it would entail the additional use of surveys, focus groups, stakeholder analyses, interviews, and other tools, at various levels of government and stakeholder groups, and is beyond the scope of this study. The first section briefly introduces the development of the country's legal framework on AQM starting with the 2004 LAAQ and relevant air quality planning instruments. It also provides a comparison of North Macedonia's air quality standards with those of the EU and the WHO. The following section describes the roles of various environmental agencies in AQM and existing coordination of responsibilities. The third section focuses on North Macedonia's capacity to monitor AAP and stationary sources. Some recent and ongoing efforts of international development partners to support AQM in North Macedonia are presented. Finally, the chapter also identifies areas for strengthening enforcement of air quality standards and offers some recommendations for improving AQM and strengthening institutional capacity of AQM in North Macedonia.

4.2 North Macedonia's Air Quality Regulatory Framework

The Government of North Macedonia has developed a comprehensive legal and regulatory framework on AQM over the last decades (Table 0.1). Specifically, the 2004 LAAQ was initially developed in line with the European Framework Directive 96/62/EEC on ambient air quality assessment and management. It has been amended several times to integrate the provisions of more recent instruments from European legislation, such as the European Framework Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe (CAFÉ Directive) and Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and PAHs in ambient air. The LAAQ specifies regulations to establish limits and target values for air quality, emission of exhaust gases from mobile and stationary sources, and substances in fuel. It also establishes the process to define alert and information thresholds, as well as short- and long-term targets for individual pollutants, and the terms to achieve them. The law gives environmental and health authorities the shared responsibility for setting limits and values for ambient air quality and emissions from stationary and mobile sources, as well as for setting the time required for the implementation of measures to improve ambient air quality. Environmental and economic authorities jointly establish the contents of harmful substances in fuels (GONM 2011).

AQM is to be conducted through ambient air quality assessments and the adoption and implementation of planning instruments that are informed by the assessments. The LAAQ mandates the environmental authority to prepare an annual assessment of air quality, based on the air quality data collected through national and local monitoring networks, and through emissions measurements of mobile and stationary sources. The environmental authority is also responsible for developing and annually reviewing lists of zones and agglomerations based on whether measured pollutants exceed, meet, or are below limit and target values (GONM 2011).

By mid-2018, the Government of North Macedonia had adopted a comprehensive series of bylaws to operationalize the LAAQ's provisions and advance transposition of additional European directives into domestic legislation. These bylaws include regulations on air quality, emissions from stationary and mobile sources, fuel quality, air quality monitoring, air quality assessments, and plans and programs. Details on the LAAQ and complementary instruments are found in Table 4.1.

Table 0.1. Development of North Macedonia's air quality regulatory framework, since 2004

Law, strategy, plan or standard	Year	Requirement
LAAQ (Official Gazette [OG] No. 67/04, 92/07, 35/10, 47/11, 59/12, 163/13, 10/15,39/16, and 99/18)	2004	Provides the backbone of the legal framework for environmental protection to approximate EU environmental standards
Law on Environment (OG No. 53/05, 81/05, 24/07, 159/08, 83/09, 48/10, 124/10, 51/11, 123/12, 93/13, 187/13, 42/14, and 44/15)	2011	Recognizes the polluter pays principle and identifies charges payable by the legal and natural person that pollute the environment as a key source of financial resources to pay for environmental projects and programs
LAAQ complementary instruments		
National Plan for Ambient Air Quality Protection (the Plan)	2013–2018	Serves as the overarching air quality planning instrument and the main instrument to ensure that the government complies with its obligations related to transboundary air pollution and other obligations stemming from relevant multilateral agreements. Includes comprehensive actions to reduce air pollution from mobile, stationary, and natural sources, with the aim of maintaining ambient air quality at levels that do not represent risks to human health or the environment. It includes measures to support local level activities to improve air quality. The Plan was adopted by the government in 2012 (published in the OG No. 170/2012) upon proposal of the MEPP and with the consent of the Ministry of Health and the Ministry of Economy.
National Program for Gradual Reduction of the Quantities of Emission of Certain Pollutants	2012–2020	Comprises specific policies and measures to progressively reduce annual emissions of key air pollutants at the national level to abate acidification, human and vegetation exposure to ground-level O_3, and soil eutrophication. Pollutants covered include SO_2, NO_x, NH_3, VOCs, carbon monoxide (CO), and total suspended particles. The program was revised for 2016–2030 but is not yet finalized.
Programs for Air Pollution Reduction and Ambient Air Quality Improvement (the Programs)		A planning instrument that comprises all the measures required to reduce the concentrations of air pollutants to meet existing air quality standards within a specified time frame. This includes the 2016 'Air Quality Improvement Plan for Skopje Agglomeration' and 'Air Quality Improvement Plan for Tetovo Municipality', and the 2012 'Pilot Program for Improvement of Air Quality in Bitola'.
Action Plan for Ambient Air Protection (the Action Plan)		An additional planning instrument that must be adopted in zones and agglomerations that exceed air quality standards

Law, strategy, plan or standard	Year	Requirement
		and target values. The action plan determines the short-term measures to reduce the risk of exceeding standards and to limit or reduce the duration of the exceedance of ambient standards or threshold alerts.

The 'Decree on the limit values of the levels and types of polluting substances in the ambient air and alert thresholds, deadlines for limit values achievement, margins of tolerance for the limit values, target values and long-term targets (OG of RM no. 50/05, 4/13)' establishes ambient air quality standards, alert thresholds, deadlines for limit values achievement, margins of tolerance for the limit values, target values and long-term targets for key air pollutants. The standards adopted by the government are similar to those of the EU, evidencing the transposition of the EU's quality directive 2008/50/EC into national legislation (Table 0.2). These air standards must be met by January 2020. Most of the standards have been set with the aim of protecting human health. O_3 is the only air pollutant that includes target values and limits to protect both human health and vegetation.

Table 0.2. Comparison of North Macedonia's national air quality standards with concentration limits set in the EU air quality directive and WHO guidelines

Pollutants	Averaging period	North Macedonia's air quality standard[a]	EU air quality directive	WHO air quality guidelines
PM_{10}	Annual average 24 hour Alert threshold (2 days)	40 µg/m^3 50 µg/m^3 150 µg/m^3	40 µg/m^3 50 µg/m^3 n.a.	20 µg/m^3 50 µg/m^3 n.a.
$PM_{2.5}$	Annual average 24 hour	25 µg/m^3 n.a.	25 µg/m^3 n.a.	10 µg/m^3 25 µg/m^3
O_3	Maximum daily 8 hour average Information threshold Alert threshold	120 µg/m^3 (long-term objective) 180 µg/m^3 240 µg/m^3	120 µg/m^3 n.a. n.a.	100 µg/m^3 n.a. n.a.
	AOT40 accumulated over May to July	18,000 µg/m^3	n.a.	n.a.
NO_2	Annual average 1 hour Alert threshold (3 hour)	40 µg/m^3 200 µg/m^3 400 µg/m^3	40 µg/m^3 200 µg/m^3 n.a.	40 µg/m^3 200 µg/m^3 n.a.
SO_2	24 hour 1 hour Alert threshold (3 hour) 10 minute	125 µg/m^3 350 µg/m^3 500 µg/m^3 n.a.	125 µg/m^3 350 µg/m^3 n.a. n.a.	20 µg/m^3 500 µg/m^3 n.a. 500 µg/m^3
CO	Maximum daily 8 hour average Maximum daily 1 hour average	10 mg/m^3 n.a.	10 mg/m^3 n.a.	10 mg/m^3 30 mg/m^3
Lead (Pb)	Annual average	0.5 µg/m^3	0.5 µg/m^3	0.5 µg/m^3
Benzene	Annual average	5 µg/m^3	5 µg/m^3	n.a.

Sources: Based on MEPP 2017, WHO 2006, EU 2008.
Note: Information threshold is a level beyond which there is a risk to human health from brief exposure for particularly sensitive sections of the population and for which immediate and appropriate information in necessary. Alert threshold is a level beyond which there is a risk to human health from brief exposure for the population as a whole and at which immediate steps are to be taken by the government. AOT4O = accumulated O_3 exposure over a threshold of 40 parts per billion.

a. Limit value to be achieved by January 2020.

Emissions from Stationary Sources

Several legal instruments regulate stationary emission sources (Table 4.3), including the rulebook[5] on the limit values for the permissible levels of emissions and types of pollutants in the exhaust gases and vapors emitted in the air from stationary sources. The rulebook covers all existing industrial and energy production installations and certain agricultural processes. In addition, guidelines have been prepared for the adequate implementation of the rulebook, directed preliminarily at industrial operators, and also at inspectors dealing with control of emissions from stationary sources, and authorities giving permits to operators. Additional rulebooks and their guidelines focus on emissions measurements (including compliance with international/European [ISO/EN] standards) and documenting and submitting emission data.

Table 0.3. Regulations on emissions from stationary sources

Name of Instrument	Publication in Official Gazette
Rulebook on the limits of permissible emissions levels and types of polluting substances in waste gases and vapors released from stationary sources into the air	OG of RM no. 141/10
Decree on determination of large combustion capacities that should undertake measures for ambient air quality protection	OG of RM no. 112/11
Rulebook on the format and content of the forms for submission of data on ambient air emissions from stationary sources, manner and time interval of submission based on the capacity of the installation, content and manner of keeping the journal of emissions into the ambient air	OG of RM no. 79/11
Rulebook on the methods, manners, and methodology of measuring the air emissions from stationary sources	OG of RM no. 11/12

Source: MEPP 2017.

Emissions from Mobile Sources

Legal instruments to control emissions from mobile sources include the ‘Rulebook for identification and assessment of the technical condition of vehicles’ (OG No. 131/09) and the ‘Rulebook on the quality of liquid fuels’ (OG No. 88/07). Verification of mobile sources’ compliance with the rulebook on the technical conditions of vehicles is conducted during the process for each vehicle’s registration and inspection. Extraordinary measures to enforce compliance by mobile sources might be taken when monitoring data or other data point at a high risk of exceedance of prescribed quality limits, target values, and alert thresholds. The rulebook on the quality of liquid fuels has been amended several times (OG No. 91/07, 97/07, 105/07,157/07, 15/08, 78/08, 156/08, and 81/09) to transpose Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels. Based on the rulebook, petrol, diesel fuels, and gas oils procured and produced in North Macedonia have met European standards on fuel quality since 2009. These include fuels used by road vehicles, as well as non-road mobile machinery and agricultural and forestry tractors (Grncarovska 2014).

[5] A rulebook is the instrument that includes the regulations on a specific subject matter.

Air Quality Monitoring, Data, and Plans

North Macedonia has developed regulations on the development of ambient air quality monitoring, air pollution emissions inventories, the cadastre of polluters and pollutants, and air quality assessments. These are complemented by regulations with specific provisions on the development of the national and local air quality plans (Table 4.4).

Table 0.4. Sublaws on the development of air quality monitoring, data, and plans

Name of Instrument	Publication in Official Gazette
Regulations on air quality monitoring and air quality assessments	
Rulebook on the methodology for the air pollution inventory and establishment of the emission levels of polluting substances into the atmosphere in tons per year concerning all types of activities, as well as other data to be submitted to the European Monitoring and Evaluation Program (EMEP)	OG of RM no. 142/07
Rulebook on the content and manner of delivery of data and information on the status of ambient air quality management	OG of RM no. 138/09
Rulebook on the methodology for ambient air quality monitoring	OG of RM no. 138/09
Rulebook on the form, methodology, and manner of keeping the cadaster of polluters and pollutants	OG of RM no. 92/10
Rulebook on detailed conditions for performance of certain types of technical activities with regard to equipment, devices, instruments, and appropriate business premises to be met by entities performing certain technical activities in the area of ambient air quality monitoring	OG of RM no. 69/11
Rulebook on criteria, methods, and procedures for ambient air quality assessment	OG of RM no. 169/13
Regulations on air quality plans	
Rulebook on the detailed content and manner of preparation of the National Plan for Ambient Air Protection	OG of RM no. 108/9
Rulebook on detailed content and manner of preparation of the plan for ambient air quality improvement	OG of RM no. 148/14
Rulebook on detailed content and manner of preparation of short-term action plans for ambient air protection	OG of RM no. 148/14

Source: MEPP 2017.

Economic Instruments

Economic instruments are a crucial element missing in the North Macedonia's AQM legal framework. The bylaws adopted to date include a wide range of 'command-and-control' instruments, which focus on preventing environmental problems by specifying how a company or individual will manage a pollution-generating process. Ambient standards, emission standards, and technology- and performance-based standards are all types of command-and-control regulations. Economic instruments are based on the polluters pay principle where the polluting party pays for the damage done to the natural environment. When designed correctly, economic instruments introduce incentives to achieve pollution reductions more efficiently. Such instruments might include taxes, pollution charges, tradable permits, or pricing policies. A number of provisions in the country's legal framework suggest that economic instruments could be introduced to tackle air pollution. In particular, the Law on Environment recognizes the polluter pays principle. It also identifies charges payable by the legal and natural person that pollute the environment as a key source of financial resources to pay for environmental projects and programs. The government is yet to take advantage of these instruments.

Environmental Permits

Environmental permits, the main instrument used to control pollution in North Macedonia, are based on the use of the IPPC, a regulatory system that employs an integrated approach to control the environmental impacts of certain industrial activities on air, water, and waste. In Europe, the IPPC is legislated through Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions. The Government of North Macedonia has started to transpose this directive through different instruments, including the Law on Environment and other secondary legislation such as the Ordinance on Determining the Activities of the Installations Requiring an Integrated Environmental Permit (OG No. 89/05) and the ordinances defining operations requiring an Elaborate,[6] either issued by the MEPP (OG No. 80/09 and 36/12) or by the local self-government units (LSGUs) (OG No. 80/09 and 32/12).[7]

Based on the IPCC legal framework, industrial activities are categorized into two groups: IPPC A and IPPC B. The IPPC A activities are related to Annex 1 of Directive 2010/75/EU[8] and are regulated and enforced at the national level. As prescribed by the European Directive, the process to obtain IPPC A permits in North Macedonia is based on the adoption of best available techniques[9] and provides opportunities for a public debate and involvement of the local population and other stakeholders.

Industrial activities that are not contemplated in the directive fall under the IPPC B category and are regulated and enforced by local self-governments. In contrast to IPPC A permits, the IPPC B permits are not based on best available technique and do not contemplate avenues for stakeholder inputs. Both types of permits determine emission limits, define monitoring and reporting requirements, and must be revised after five years (Pokrovac, Douma, and van der Velde 2015).

4.3 Organizational Structure for Air Quality Management

The MEPP has been the country’s formal environmental authority since its establishment in 1998 with responsibility for developing environmental policies, including efforts to transpose EU Directives that are part of the environmental acquis. The MEPP’s ambitious mandate includes managing all types of pollution, including air pollution, and monitoring environmental quality. To fulfill this mandate, the MEPP has 200 employees.

MEIC, a department within the MEPP, is responsible for providing relevant and properly processed (systematized and standardized), comprehensive, precise, transparent, and easily accessible information on the state, quality, and trends in all environmental media (water, air, noise, and waste). Among its multiple responsibilities, MEIC is in charge of ambient air quality monitoring, including validation and verification of data, regular maintenance and servicing of stations and samplers, and manual calibration of instruments in monitoring stations. Based on the data collected through the State Automatic Ambient

---

[6] An ‘Elaborate’ is a description of the installation and the relevant prescriptions applicable to environmental media that must be submitted for activities and works that are not subject to the Environmental Impact Assessment procedure.

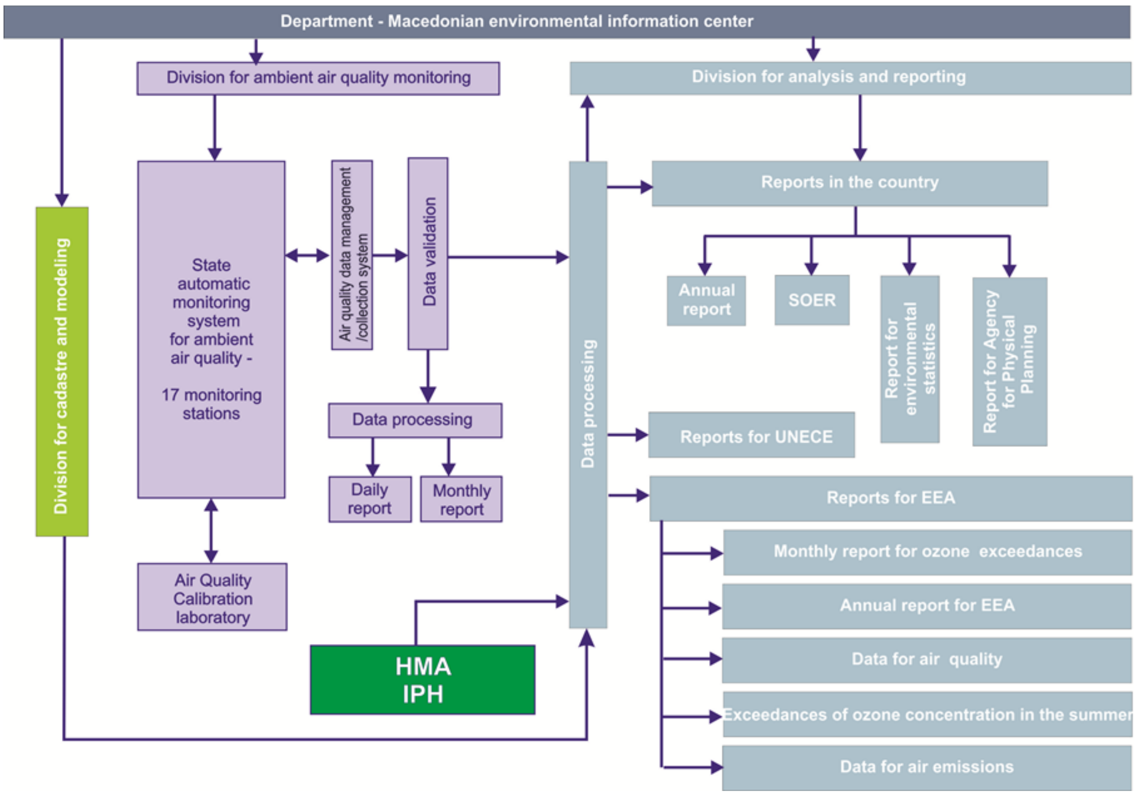
[7] Local self-government units refer to the governments of municipalities and the City of Skopje.

[8] Industrial activities contemplated in the directive’s annex include energy industries, production and processing of metals, mineral industry, chemical industry, and other activities (industrialized production of pulp, paper, and large-scale textile and tanneries operations).

[9] Best available technique is defined by Directive 2010/75/EU as “the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole.” (Article 3.10).

Air Quality Monitoring System (SAAAQMS), MEIC prepares daily, monthly, and annual reports on the country's air quality (Interreg 2018). MEIC is also the single national entity (SNE) responsible for the preparation of national emission inventories under the CLRTAP (MEPP 2017). Four different units within MEIC contribute to activities related to air quality monitoring: Unit for Air Quality Monitoring (which manages the SAAAQMS), Unit for Analysis and Reporting, Unit for Cadasters and Modeling, and Unit for Information Technology (Figure 4.1). Each unit has limited number of staff (for example, only four people were employed in the Unit for Air Quality Monitoring in 2018). MEIC annually receives about one-third of the budget required for adequate operation and maintenance of the air quality network.

Figure 0.1. Organization and activities of MEIC



Although MEIC's formal mandate focuses on environmental information, it has also assumed a key role in developing and implementing air quality policies, legislation, standards, and projects. For instance, MEIC has led the preparation of the National Plan of Air Protection and for supporting municipalities in the preparation of air quality action plans and programs (Lanzani 2010).

The Administration for Environment, also part of MEPP, includes five sectors (Environment, Industrial Pollution and Risk Management, Nature, Water, and Waste), which in turn comprise several units. The units that are more directly involved in air quality and emission control are the Laboratory Unit (Environment Sector) and the Unit for IPPC (Industrial Pollution and Risk Management Sector).

Other important players related to AQM are listed in Table 4.5.

Table 0.5. Responsibilities for AQM aspects across sectors

State Environmental Inspectorate (SEI)	Responsible for enforcing the LAAQ and its regulations, as well as other measures adopted to protect air quality. SEI became an independent legal body in 2014 with own budget but remains under the leadership of the MEPP. As of 2016, SEI had a total staff of 26 people, inadequate for advanced assessments on pollution's health impacts (FMI and MEPP 2017).
Ministry of Health	Through the Institute for Public Health and Centers for Public Health, participates in the monitoring of air pollution, monitoring and assessment of risks from air pollution, and protection of the population from the harmful effects of air pollution.
Ministry of the Economy	Responsible for monitoring fuel quality and for collecting and summarizing national fuel quality data. The quality of liquid fuels that are placed on the domestic market by suppliers is monitored on the basis of an annual fuel quality monitoring plan according to the turnover in the preceding year, per liquid fuel. Providers are responsible for covering expenses for monitoring the quality of liquid fuels. The quality of the fuel is considered as suitable if it possesses the qualitative characteristics determined by the rulebook on the quality of liquid fuels.
LSGUs	LSGUs have competence for the development of planning instrument for air quality protection. In particular, LSGUs are responsible for developing and implementing air quality improvement programs and short-term action plans in zones and agglomerations where air pollution exceeds the emission limit values. LSGUs also have the power to establish local monitoring networks for air quality.

Although several organizations contribute to AQM in North Macedonia, all of them are severely understaffed. For instance, as of 2017, only one person was engaged full time to work on activities related to inventories. Additional staff are needed to implement the quality system, air quality awareness raising activities, and monitoring of air quality improvement plans.

4.4 Coordination of Air Quality Management: Roles and Responsibilities

Given that air pollution stems from a broad range of sectors, intersectoral coordination is a fundamental pillar of AQM. In North Macedonia, an intersectoral working group on air quality was established in 2012 (coordinated by the MEPP), with participation from government institutions that have responsibilities for the creation of relevant policies, planning and strategic documents, financial plans, economic instruments, and capacity building: Ministry of Agriculture, Forestry and Water Economy; Ministry of Economy; Ministry of Transport and Communications; Ministry of Health; Ministry of Finance; and Ministry of Interior.

In September 2017, this group continued to work under the leadership of the Deputy Minister of the MEPP. Representatives from nongovernmental organizations (NGOs) and the City of Skopje were included in this group for the first time. The working group meets more frequently during the winter months, when pollution is more severe and constitutes the key forum to discuss problems faced by the different institutions in fulfilling their AQM-related responsibilities. Based on the working group's meeting, the MEPP assigns to different institutions concrete responsibilities for implementing air quality measures, which are also submitted to the Government of North Macedonia for their adoption. Up until 2018, the working group has mostly focused on short-term measures to improve air quality.

Although the relationship between different levels of government is good, as evidenced by the MEPP's support to local governments in the development of air quality action plans, limited human resources at most LSGUs represent a significant challenge to ensure a stronger alignment.

4.5 Monitoring and Reporting of Ambient Air Pollution

Two main sources of air quality information in North Macedonia are (a) air quality data generated by monitoring stations located throughout the country and (b) direct measurements at stationary sources (that is, owners of the emitting facilities[10] are responsible for installing and maintaining measuring instruments at the source).

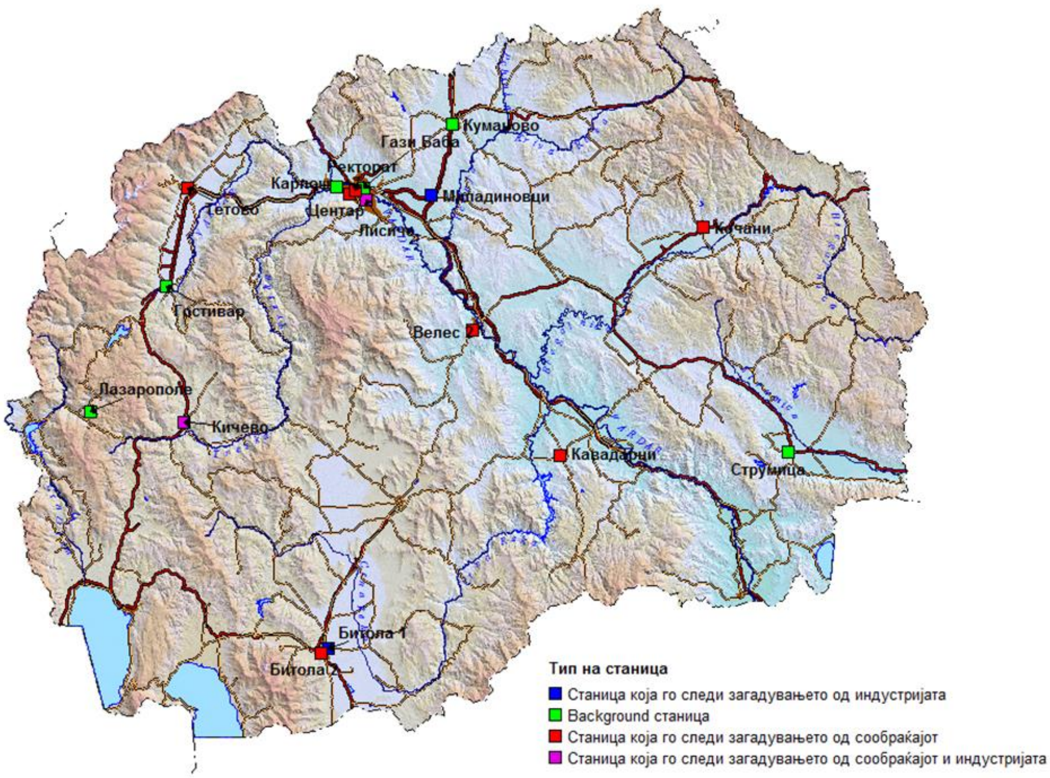
According to Article 37 of the LAAQ, the MEPP (specifically the Division for Ambient Air Quality Monitoring within MEIC of the MEPP) is responsible for the operation and maintenance of the national ambient air quality monitoring network. The government has established a national ambient air quality monitoring network (SAAAQMS), with the first stations becoming operational in Skopje in 1998. Today, the network consists of 17 air quality monitoring stations and 1 mobile monitoring station, all of which are equipped with automatic measurement instruments, connected with the air quality database located in the MEPP. In addition, the Institute of Public Health manages a network with 10 air quality monitoring stations (MEPP and EEA 2018; Stefanovska 2018).

A calibration laboratory for air quality was established in 2004 for regular maintenance and calibration of the instruments. The laboratory has capabilities for calibration of the referential analyzers using primary static injection system, identification of correlation between the primary calibration method and other methods used, secondary dynamic system for attenuation, benchmark gases, field calibrator, and participation of interlaboratory benchmarking measurements.[11] This capacity should be expanded to include chemical analyses for source apportionment (such as heavy metals and major ions in PM samples, VOC, PAH, NH_3).

The locations of air quality monitoring stations are shown in Figure 4.2.

[10] Installations with an installed power of 0 to 50 MW must submit the information annually, while those with a capacity above 50 MW must do so on a monthly basis.
[11] Information received from the government counterparts on June 2018 upon request.

Figure 0.2. Location of fixed air quality monitoring stations operated by the MEPP



In Skopje, monitoring stations are located in Centar, Karpos, Rektorat, Gazi Baba, Lisice, and Butel (Table 4.6). Other stations are found in Miladinovci (next to an oil refinery near the City of Skopje), Kumanovo, Kochani, Veles, Strumica, Kavadarci, Tetovo, Gostivar, Kichevo, and Lazaropole. The city of Bitola has two stations: AMS Bitola 1 UHMR and AMS Bitola 2 Strezevo. The number of monitoring stations at the national level is in accordance with the requirements of the national legislation and European directives. However, there is a need to assess the location of monitoring stations to ensure good spatial coverage that captures the impacts of major industrial emissions in addition to urban emissions. Despite recent replacement of some instruments at several stations, the overall network might benefit from upgrading.

Table 0.6. Air quality monitoring stations in Skopje

No.	Station name	Station type	Parameters monitored	Remarks
1	Karpos	Urban background	O_3, NO_2, SO_2, CO, PM_{10}, $PM_{2.5}$, benzene, toluene, and xylene	Operational since September 2011
2	Centar	Urban traffic	O_3, NO_2, SO_2, CO, PM_{10}, $PM_{2.5}$, benzene, toluene, and xylene	Operational since September 2011
3	Lisice	Industrial/residential	O_3, NO_2, SO_2, CO, and PM_{10}	Operational since 1998. The station is positioned close to a major intersection and a cement factory is 1.2 km to the southwest of the

No.	Station name	Station type	Parameters monitored	Remarks
				station and a quarry at a distance of 1.8 km.
4	Rektorat	Urban traffic	O_3, NO_2, CO, PM_{10}, benzene, toluene, and xylene	Operational since April 2004.
5	Gazi Baba	Suburban background	NO_2, SO_2, CO, and PM_{10}	Operational since 1998. The station represents the overall city background concentrations influenced by the integrated contribution from all sources.
6	Butel	Mobile	O_3, NO_2, SO_2, CO, PM_{10}, $PM_{2.5}$	Mobile station

Monitoring stations within the SAAAQMS measure concentrations of SO_2, CO, NO_2, PM_{10}, $PM_{2.5}$, and O_3, and information on pollution levels is available in real time to authorities and the public.[12] The network also conducts indicative measurement of heavy metals. Validation of hourly data is performed on a monthly basis (at the beginning of each month), while no validation check of daily data is performed.

While most of the stations monitor PM_{10} concentrations, $PM_{2.5}$ data are not sufficient for proper air quality assessment at the national level due to the limited number of measurement sites.[13] This is a cause of concern because $PM_{2.5}$ is the pollutant that causes the most significant adverse health effects and inconsistent air quality data hampers the government's capacity to make evidence-based decisions and adequately inform the population about potential health risks. There is a need for consecutive PM_{10} and $PM_{2.5}$ measurements to be conducted at more stations in the future. It is also recommended to extend monitoring to include precursors of secondary aerosols such as NH_3 and VOCs as well as chemical speciation of PM including major ions (such as sulfate and nitrate) and heavy metals at selected locations to produce data for source apportionment studies.

According to the LAAQ, local authorities may establish local monitoring networks with the approval of the national environmental authority. In such cases, local authorities have an obligation to submit monitoring data and information to the national authority. In turn, the national authority has the obligation to submit reports as requested by national and regional health authorities, the organization in charge of hydrometeorology, local governments, and other public agencies (GONM 2011).

Capacity for Monitoring

The financial resources to implement all AQM activities, including monitoring, must be provided by the budget of the responsible national or local government. The budget for operation and maintenance of the air quality monitoring system is defined within an annual operational program that outlines the necessary staff and financial recourses for its functional operations. Around MKD 30–40 million (€500,000–650,000) is planned for operation, upgrade, and maintenance of the monitoring stations on an annual basis. However, between 2014 and 2016, only 31–42 percent of the requested funds were approved.

[12] Data from the air monitoring stations are available at http://air.moepp.gov.mk/.
[13] For 2013–2017, $PM_{2.5}$ is only available at two stations (Centar and Karpos); limited monitoring of $PM_{2.5}$ concentrations is also available in Bitola 2, Kumanovo, and Tetovo stations (for half of the year in 2017). In 2017, $PM_{2.5}$ measurements were introduced in four new locations; for a total of six locations fine PM is monitored.

Budget restrictions are a major obstacle to adequately operate and maintain the air quality monitoring network and calibration laboratory. A lack of regular maintenance of instruments, spare parts, calibration gases, and consumables for the aging instruments have already decreased data coverage, resulting in significant problems with continuous availability of reliable information on air pollution. In addition, lack of IT-trained personnel and the existing database, which lacks a user-friendly interface for data management, poorly affect air quality reporting in North Macedonia. Similarly, lack of funding has constrained chemical and emission laboratory activities, as well as the maintenance and calibration of weather stations that are fundamental to improve AQM, given the strong influence of local meteorological and topographic conditions on local air quality and its seasonal variations, particularly in cities such as Tetovo (FMI and MEPP 2017). Limited resources threaten the sustainability of efforts undertaken in recent years to strengthen the laboratory's capacities and the implementation of quality assurance and quality control procedures, which depend entirely on the timely allocation of funds for the operation of the system. It is recommended that additional funding resources are provided to operate and maintain air quality monitoring network, including adequate human capacities.

4.6 Public Disclosure of Air Quality Information

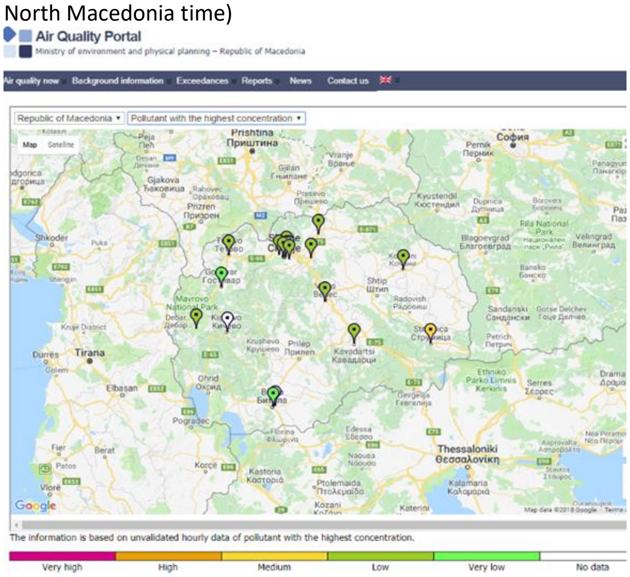
The LAAQ includes various provisions on stakeholder engagement at the national and local levels. MEIC has an obligation to publish annual reports on emissions and ambient air quality and periodical reports on the implementation of obligations deriving from the LAAQ. Both national and local governments are required to disseminate information on implemented measures, air quality within their jurisdictions, and activities planned for the following year.

The LAAQ mandates the establishment of an emissions inventory, which is considered a key source of information to meet the government's obligations under the CLRTAP and its protocols. The MEPP is required to prepare an annual report on the emissions from the inventory, including information on changes in the geographical distribution of emissions across the national territory (GONM 2011). Information about pollution concentrations is also available to the public. Throughout the years, the MEPP has gradually strengthened the methods to develop its inventory. For instance, the 2016 inventory included a recalculation of all pollutants and time series from 1990 based on improved methodologies and the 2017 inventory included emissions of BC and uncertainty trends for the first time (MEPP 2018).

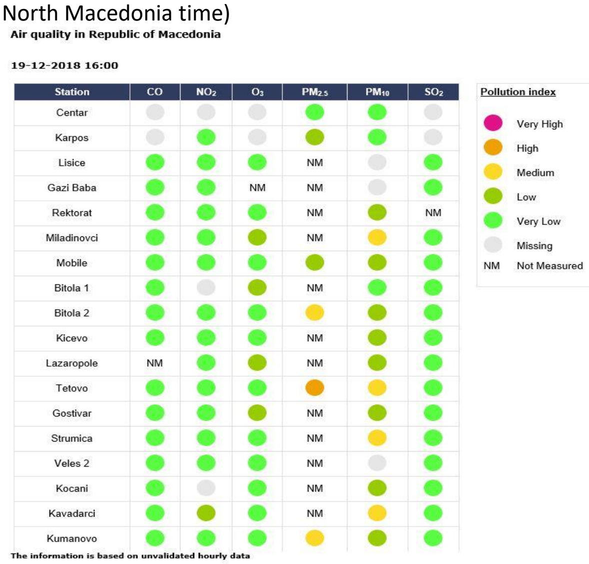
Information about AAP concentrations is also available to the public (Figure 4.3).

Figure 0.3. Example readings of air quality from the online network

Air quality based on worst pollutant on June 18, 2018 (20:00 North Macedonia time)



Air quality of main pollutants on December 19, 2018 (17:00 North Macedonia time)



Source: North Macedonia Air Quality Portal 2018, http://air.moepp.gov.mk.

The LAAQ requires the establishment of a cadaster of air polluters and pollutants, as part of the national environmental cadaster. Data in the cadaster must be publicly available and include information on the facility's location, activities, and technical and technological processes; relevant data on pollutant emissions; and measures and controls that have been adopted to reduce pollution emissions. The National Cadaster of Air Polluters and Pollutants was first developed in 2004 and updated in 2009. The cadaster was initially developed to include a wide range of data (identification of polluters, description of technological processes, electricity consumption, and so on); however, since 2009, the cadaster only gathers information on emissions data due to capacity constraints (MEPP and EEA 2018).

4.7 Enforcement of Regulations

LSGUs have their own inspectors to enforce environmental laws and compliance with relevant regulatory instruments, including IPPC B permits. These inspectors were created as a result of the adoption of the 2011 Law on Environment. By 2015, all of the 81 municipalities in North Macedonia had appointed environmental inspectors. However, in many of them, the same person was also responsible for other kinds of inspections and was often responsible for the issuance of IPPC B permits and other documents (Mallada et al. 2015). A 2015 assessment found that LSGUs generally lacked adequate human capacity in terms of number and skills, which was aggravated because their competences were spread among too many issues. These conditions resulted in a low level of supervision of environmental compliance and the virtual absence of adoption of enforcement measures, which was closely associated with uncontrolled emissions by large number of facilities under the jurisdiction of local authorities (Pokrovac, Douma, and van der Velde 2015).

4.8 Recent and Ongoing Efforts of Development Partners to Support Air Quality Management in North Macedonia

North Macedonia's air quality institutions are severely understaffed, both at national and local levels, but the current government has expressed a strengthened commitment to reducing air pollution and is coordinating with donors and international partners to build the financial base for enacting and implementing policy changes. Various development partners are already supporting the government's capabilities in AQM. The EU-funded twinning project 'Further strengthening the capacities for effective implementation of the acquis in the field of air quality' concentrates on further improving the capacities of the MEPP, National Public Health Institute, and local municipalities. It is being carried out with the Finnish Meteorological Institute and the Environment Agency of Austria as the EU member state partners (Twinning Project Newsletter 2015). One of the focus areas of the current project is the development of local-level air quality improvement plans for Skopje (including measures to improve the air quality in long term) and Tetovo. The project also provided important assistance in preparation of the MEPP Air Quality Assessment Report for the Period 2005–2015 (MEPP 2017). In addition, dispersion modeling studies will be performed to assess the air quality impact of, for example, traffic and the industry. The models used are the local (urban dispersion model [UDM-FMI], and road network dispersion model [CAR-FMI]) and regional (system for integrated modeling of atmospheric composition [SILAM]) scale models developed by the Finnish Meteorological Institute (FMI) for assessment of levels of air quality (MEPP 2017). Furthermore, the capacities of health impact assessment of AAP have been enhanced under the health component of the project.

This study found the following development partners working directly and tangentially on AQM in North Macedonia.

The Government of Germany. Germany is supporting investments in the energy sector, specifically on district heating, renewable energy, and energy efficiency. As part of a €38 million project, the Kreditanstalt für Wiederaufbau Development Bank is supporting a district heating project in Bitola, which aims to reduce air pollution. Other actions are focused on installing a wind farm in Bogdanci (€48 million for phase 1 and €18 million for phase 2). As part of technical assistance, the government supported the development and implementation of a monitoring process of partner countries' National Energy Efficiency Action Plans, including a monitoring and verification platform (€16.3 million, 2008–2019). Awareness raising of the benefits of environmental protection was supported through some climate funds (around €30,000).

The British Embassy. Support from the British Embassy is focused on the energy sector and technical support for the development of a National Energy Development Strategy (August 2018–March 2019), which aims to contribute toward a modernized and transformed energy sector in line with EU and regional policy, contributing to increased access, integration, and affordability of energy services, leading to reduced local and regional pollution and increased private sector participation.

The Government of Sweden, through the Swedish Environmental Protection Agency, is preparing to support North Macedonia's MEPP in the areas of nature protection, air pollution, and EU negotiation. On air pollution, the project aims to improve the national system of monitoring and reporting of air pollution (€500,000 for monitoring equipment; €300,000 for technical assistance).

The Government of Switzerland. Actions by the State Secretariat for Economic Affairs and the Swiss Agency for Development and Cooperation are focused on the waste management and building sector. The Swiss Embassy is also promoting a small action (CHF 50,000) on cycling as an alternative mode of transport for students in North Macedonia (Velo Schools, September 2018–June 2020).

Some planned international efforts to support AQM in North Macedonia are presented in Table 4.7.

Table 0.7. List of planned projects to support AQM

Project title	Program	Period	Funding Amount	Expected outcomes
Transboundary Air Pollution Health Index Development and Implementation	INTERREG IPA CBC 2014–2020 Republic of Greece – Republic of North Macedonia	Q3/2018–Q3/2020	€958,331.00 (EU)	• Development of regional emission inventory • Assessment of the contribution of each emission sources • Development of air quality plan for Bitola • Purchase of one monitoring station and analysers • Heavy metals and PAHs indicative measurements • Survey for emissions for households heating - Gevgelija • Joint study for comparative analysis for the Cross Border Cooperation (CBC) area • Health impact assessment of AAP and assessment of health gains from implementation of targeted policies to reduce exposure levels • Development of air quality public health index • Air quality and health sensitization campaign
Support in the Implementation of Air Quality Directives and Horizontal Legislation	IPA2	Q3/2019–Q3/2021	Total €2,000,000.00 (€1,700,000.00 EU and €300,000.00 national contribution)	• Completion of the legal framework for air quality in line with the requirements of the EU acquis (2004/107/EC, 2016/2284/EC, 2008/50/EC) • Preparation of planning documents for air quality improvement (National Plan for the Protection of Ambient Air for 2020–2024) • National Air Pollution Control Program for 2020–2030 and emission projections with basic scenario and scenario with measures • Strengthening the administrative capacities for assessment, monitoring, and analyses of air quality and pollution (training and conducted measurements according

Project title	Program	Period	Funding Amount	Expected outcomes
				to HM, CAFÉ Directive, and EMEP protocol)

4.9 Conclusions and Recommendations

Strengthen the Legal and Policy Framework for AQM

Although the government has advanced significantly to achieve the full transposition of the EU environmental acquis into domestic legislation, a few gaps remain such as transposing the most recent European legislation on industrial emissions (Pokrovac, Douma, and van der Velde 2015). Another evident gap in the legal framework is the lack of an air quality standard for $PM_{2.5}$ concentrations that must be achieved on a daily basis. This gap is also present in the EU Directive 2008/50/EC. However, the WHO does include a $PM_{2.5}$ daily standard and interim targets that could be adopted in North Macedonia (WHO 2006).

In addition, it is recommended that the government revise and strengthen the legal framework to reduce pollution from domestic heating, stationary sources, and mobile sources:

- **Domestic heating.** Burning of coal and wood for heating is a key source of air pollution, particularly during the winter months. In 2017, the government announced that coal heating would be banned by 2020.[14] However, the use of dirty fuels is a socially sensitive issue: a large share of the population cannot afford cleaner sources of heating. Given the severity of air pollution from these sources, the government could start with implementing a pilot program to substitute traditional stoves with more efficient ones in the short term. Lessons from such a pilot and other existing initiatives could be considered to inform the development of a possible large-scale stove replacement program. This would help reduce emissions from domestic heating while medium- to long-term options (for example, expanding district heating) can be developed. In many countries, these types of programs have been implemented with targeted subsidies and/or donor support given that project beneficiaries cannot afford to pay the full costs of substituting their stoves with more modern alternatives. A public awareness program would help educate the public on the purpose of stove replacement, low-emission stove use, and available resources for households, and promote adoption of clean stoves in households.
- **Stationary sources.** Key air pollution emission sources include emissions from industry and energy generation (particularly the two thermal power plants REK Bitola[15] and REK Oslomej, and facilities for the production of ferroalloys). Ongoing efforts to ensure that large polluters—particularly in production of ferroalloys, cement, iron and steel, and others—adopt plans to gradually reduce their emissions and comply with environmental standards should be continued and strengthened, including by requiring installation of pollution abatement equipment and emissions control technology in production facilities. The government could provide financial incentives for smaller industrial undertakings to strengthen AQM. In thermal power plants, measures such as setting consumption caps to gradually reduce coal use; incorporation of new technologies for desulfurization and denitrification; and setting resource and energy conservation goals for

[14] http://meta.mk/en/makraduli-the-coal-heating-will-be-banned-by-2020/.
[15] According to the Health and Environmental Alliance, in 2016 the Bitola power plant was the second largest emitter of $PM_{2.5}$ among all power plants across Europe (HEAL 2016).

resource-intensive industries could be considered. In addition, efforts to reduce air pollution should incorporate the use of sanctions for polluters that exceed their approved emission level. Sanctions should be clear and commensurate with the damage caused by polluters. Furthermore, the National Program for Gradual Reduction of the Quantities of Emissions of Certain Pollutants (2012–2020) currently focuses on abatement of acidification, human and vegetation exposure to ground-level O_3, and soil eutrophication. As the program undergoes revision for 2016–2030, it could be broadened to incorporate PM, including $PM_{2.5}$, which is currently not covered by the program.

- **Mobile sources.** The existing framework in North Macedonia contemplates the verification of mobile sources' compliance with the rulebook on the technical conditions of vehicles during the process for each vehicle's registration and inspection. However, in reality, these inspections have not helped reduce vehicle emissions from the obsolete and growing fleet. Developing countries have successfully implemented comprehensive policy reforms and investments to reduce pollution emissions from mobile sources that could be adopted in North Macedonia (see China case).

In addition, economic instruments should be considered where applicable to move existing markets and policies toward improved environmental outcomes. While the Law on Environmental Protection contemplates the creation of air pollution taxes, these have not been developed. The government should consider taxes based on fuel efficiency standards, with higher taxes imposed on less fuel-efficient vehicles. Similarly, market-based instruments could provide an efficient mechanism to reduce pollution emissions from different sources over the medium term. Pollution charges, if designed and planned effectively, can promote a shift from using highly polluting fuels such as coal and diesel to cleaner fuels such as natural gas. An essential input for fuel taxes or pollution charges design is the targeting of fuels according to pollutants (Sanchez-Triana et al. 2014). Further studies should be carried out to assess the distributional impacts of these measures and propose mechanisms to mitigate any regressive effects.

Build Capacity to Design, Implement, and Enforce AQM Policies

A top short-term priority for North Macedonia is to build capacity to design and implement AQM policies, including recruiting a higher number of specialized staff. The organizational structure requires specialists who can carry out a range of actions, including monitoring, enforcement, health impact assessment, and planning. Recruiting staff with necessary expertise and background is paramount to ensure that the MEPP and public health institutions can fulfill their responsibilities. The government might revise the current organizational structure to incorporate units that are specifically dedicated to developing, implementing, monitoring and evaluating air quality laws, policies, programs, and projects. Although MEIC has assumed these responsibilities, its capacity to fulfill this role and its formal mandate is constrained.

There is also a need for systematic and objective evaluations to be conducted periodically in North Macedonia to assess the efficiency, effectiveness, impact, and sustainability of national and local air quality strategies and plans. The information provided by evaluations is key to incorporate lessons learned into decision making, as well as to hold governments accountable for results (MFA 2009; OECD 2010).

Strengthening institutional capacity to enforce existing air pollution limits is another pressing priority. The government should prioritize expanding the number of inspectors and provide them with training and resources to conduct field investigations. Sustained, higher resource allocation will be key to improve enforcement of existing air quality laws and regulations. In addition, building capacity to enforce air pollution legislation requires bolstering the capacity of courts and judges, and of inspectors to provide sound technical evidence of infractions. Tested approaches to address noncompliance with environmental legislation include publicly disclosing emitters' compliance with environmental standards to generate social pressure against violators. Over the medium term, there is a need to clarify and expand the range of sanctions for noncompliance and increase fines. Regulations establishing mandatory monitoring and inspection programs that are strictly enforced should be considered.

Invest in a Robust Air Quality Monitoring Network, Emissions Inventory, and Modeling Capabilities

Investing in a robust air quality monitoring program is essential to understand fully the risks generated by air pollution and the effectiveness of government interventions carried out to address it. While North Macedonia has made progress in establishing an air quality monitoring network, lack of funding threatens the sustainability of the efforts undertaken in recent years to strengthen monitoring capacities. There is a need for ongoing training and budget to adequately staff institutions responsible for maintaining and utilizing the AQM network and laboratory. In addition, resources must be allocated to develop and implement quality control and quality assurance protocols that ensure the validity of the data.

More specifically, the government should

- Ensure the geographic extent of the air quality monitoring network is sufficient, especially to fill current data gaps, and the network reliably and consistently monitors pollutants such as $PM_{2.5}$, SO_2, NO_x, across the country; and
- Consider expanding monitored pollutants to include O_3, lead, and other pollutants such as heavy metals concentrations (particularly in Skopje, Tetovo, and Kavadarci) and PAH measurements in urban areas. In addition, given the common practice of burning solid fuels in North Macedonia, monitoring could also be expanded to include chemical constituents of PM such as organic carbon, elemental carbon, BC, NH_3, VOCs, and PAH.

Strengthen Stakeholder Engagement

Experiences from across the globe show that stakeholder engagement is crucial to reform and bolster environmental actions, particularly when well-articulated constituencies can demand improved governmental responses to a clearly identified priority issue (Ahmed and Sanchez-Triana 2008). Different agencies within the Government of North Macedonia invite stakeholders to participate in the process of drafting new strategies and programs, particularly after the creation in 2017 of a new intersectoral working group. While there's value in such consultative events, maintaining stakeholder engagement and networks after completing a policy formulation exercise is crucial for long-term learning and dialogue (Blair 2008).

To strengthen stakeholder engagement, the government should consider

- Establishing an official air quality advisory board, comprising representatives from a broad range of stakeholders, including practitioners, academics, and others, to periodically discuss the development and the implementation and evaluation of actions to improve air quality;

- Creating a strong air quality constituency by providing training and disseminating specific materials among policy makers, legislators, NGOs, journalists, and other stakeholders;
- Adopting a public disclosure scheme to foster accountability requiring industries to report their polluting emissions and rate themselves on compliance with national standards; and
- Strengthening intersectoral coordination to include priority setting, design and implementation of interventions, and monitoring and evaluation of effectiveness of intersectoral coordination mechanisms.

Chapter 5. Learning from International Experience in Tackling Air Pollution

5.1 Introduction

Air pollution by nature cuts across activities of various sectors of the economy and geographic boundaries, and respects no age group of persons. Addressing such a cross-cutting problem effectively requires concerted and sustained, multidisciplinary, and cross-sectoral efforts that engage a broad range of stakeholders including the government, civil society, academia, private sector, and international development partners.

The complexity of air pollution calls for a strategic and integrated approach that is based on a comprehensive understanding of the air pollution problem and solutions appropriate to the specific context of the affected city or country. The complexity of air pollution is borne out in the varying levels of progress that cities in developed and developing countries have made in improving air quality and the time frames within which such progress has been achieved. For illustrative purposes, it took about 50 years for cities in the United States to achieve the WHO air quality guideline value for PM_{10}—they went from an average value of 60 μg/m^3 in the 1960s to around 20 μg/m^3 in the 2010s (World Bank 2012). Cities in developing countries are also recording progress in their efforts to reduce AAP and the results show that with government commitment and sustained and focused efforts, it is possible to achieve improved air quality outcomes and in shorter time frames (Table 5.1). These country experiences and results lend support to optimism for similar positive progress in North Macedonia.

Table 0.1. $PM_{2.5}$ and PM_{10} reduction in selected cities

City, Country	Highest concentration	Reduction	Time Frame
Mexico City, Mexico[16]	PM_{10} = 180 μg/m^3	>70%	25 years (1990–2015)
Lima - Callao, Peru[17]	PM_{10} = 85 μg/m^3	>50%	8 years (2006–2014)
Beijing, China[18]	$PM_{2.5}$ > 89 μg/m^3	>30%	4 years (2013–2017)
Ulaanbaatar, Mongolia[19]	$PM_{2.5}$ = 250 μg/m^3	>60%	6 years (2009–2015)

This chapter presents cases illustrating how different countries have addressed, with World Bank support, air pollution from various sources using a variety of interventions including policy reforms, investments, knowledge development, and technical assistance; and various policy instruments such as command-and-control, economic, and market based. The chapter draws lessons learned from the experiences of, and approaches used in, these countries, which underscore the need for integrated, strategic, and context-specific approaches to tackle AAP. The examples also demonstrate how the World Bank has played an integrative role in supporting countries in addressing a complex issue as air pollution. It is envisaged that the discussion in this chapter could provide a background to inform potential and ongoing efforts of the

[16] Air Quality Mexico City, Experience 1990–2018. Presentation by Rodolfo Lacy, Government of Mexico. Presentation in Delhi, March 2018

[17] Based on Macizo and Sanchez (forthcoming).

[18] ICCS 2018

[19] Based on communication between World Bank staff member and Prof. S. Lodoysamba (retired) of the National University of Mongolia and air quality monitoring results provided by the Ministry of Environment and Tourism in Mongolia for 2008–2015.

World Bank and other development partners in supporting North Macedonia's actions to reduce air pollution in a way that ensures that those efforts are strategic, integrated, and complementary.

5.2 Global Experiences in Tackling Air Pollution

Tackling Air Pollution from Domestic Heating in Mongolia

Background. Ulaanbaatar, Mongolia is among the cities with the worst air quality in the world. PM might be responsible for up to one in five deaths in the city. Air pollution is particularly poor in Ger[20] areas surrounding Ulaanbaatar where about two-thirds of the city's 1.4 million inhabitants live. Annual average ambient concentrations of PM pollution can range from 200 to 350 $\mu g/m^3$. Air pollution is particularly severe during the winter months, when households burn coal and wood for heating and cooking, releasing polluting emissions at breathing height (2–3 m above ground). During this season, $PM_{2.5}$ concentrations can exceed the WHO guideline for daily average concentrations (25 $\mu g/m^3$) by 120 times.

Plans to establish a stove replacement program in the Ger areas were initially met with resistance from city government officials who were not convinced that a stove replacement/removal program, which could be conducted in the short term, should be prioritized and felt that alternative long-term options would be more economically effective. The government, with World Bank support, decided to undertake full-scale AQM planning to obtain a complete understanding of sources, concentration levels, and health impacts and identify the most economically effective abatement options for reducing air pollution in the short, medium, and long term. The World Bank mobilized grant funding, totaling about US$1 million, from several sources to provide technical assistance to the Government of Mongolia, which was underpinned by the Ulaanbaatar Air Monitoring and Health Impact Baseline (AMHIB) study conducted between 2008 and 2011.

The three-year technical assistance entailed (a) redistribution of air quality monitors across Ulaanbaatar to cover the central area, as well as the Ger areas, which were previously not monitored; (b) one full year of air quality monitoring at all locations to allow for capture of seasonal variations; (c) establishment of an inventory of emissions from all major sources in the city, air pollution modeling, and estimation of population exposure to PM pollution; (d) a health impact assessment in Ulaanbaatar to establish a baseline for health impacts as well as local (Ulaanbaatar) dose-response relations between PM concentrations and various health end points; and (e) identification of economically effective interventions.

Process. The development of AMHIB entailed an extensive process of bringing together and engaging various stakeholders who were already working on air quality in Mongolia as well as integrating new stakeholders to fill knowledge and technical gaps in the process. At the time of the study, several development institutions were engaged on different elements of AQM planning (see Figure 5.1) in the country. The comprehensive scope of the AMHIB study and the World Bank's role in leading it in collaboration with the government resulted in a process where the World Bank played a central role in technical coordination of the AQM planning process. It also played an important role in administrative coordination of the engagement of diverse stakeholders including national (various ministries including health, energy, transport, housing, urban development; the Ulaanbaatar city departments; and academia) and international (agencies of Japan, Germany, France, and Republic of Korea) institutions, and in

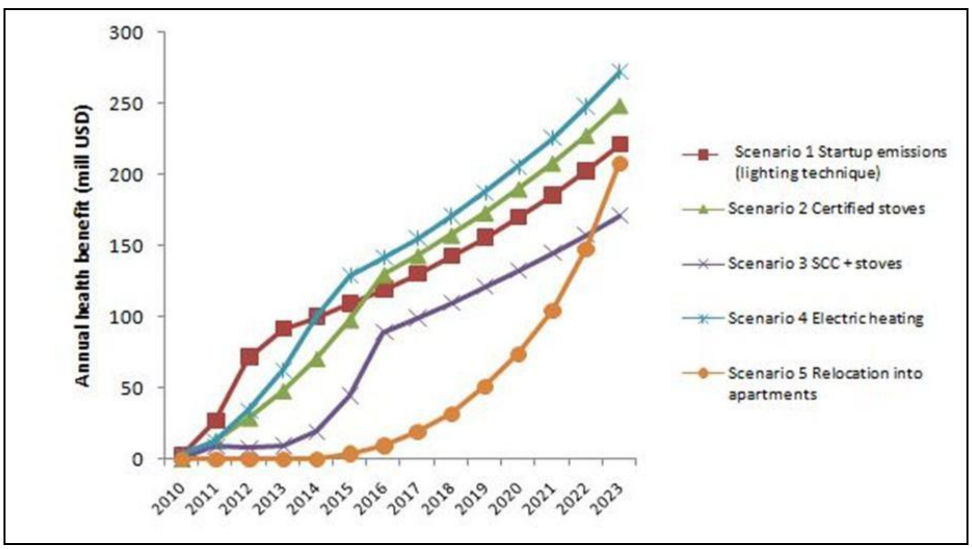
[20] Portable wooden homes traditionally used by Mongolian and other Central Asian nomads.

engaging international expertise (on epidemiology, health research, economists) in the AQM planning process.

Actions. The AMHIB study established that small stoves in about 150,000 Gers, at the time of the study, were the main source of PM in Ulaanbaatar and examined nine options for reducing air pollution: (a) reducing start-up emissions by backlighting the fire, (b) reducing start-up emissions through stove modifications, (c) replacing existing stoves with cleaner stoves and no fuel change, (d) replacing existing stoves and fuel with cleaner stoves and semicoked coal; (e) installing electric heating in Ger homes, (f) relocating Ger households into apartment buildings, (g) improving heat-only boilers, (h) cleaning street to reduce road dust suspension, and (i) greening urban areas to prevent dust suspension.

Of the initial nine options, five were found to provide the highest health benefits (Figure 5.1). The abatement options that provided the highest net benefit—that is, monetary value of reduced health impact minus the cost of the abatement—were also examined. The immediate term option with the stove start-up modification gave the highest net benefit, while improved stoves and fuels and the medium-term option with electric heating in the Gers gave significant benefits. The long-term option of moving Ger households into apartments was costly while street cleaning and city greening had only limited health benefits. Realizing the health benefits lost (that is, the cost of not applying immediate abatement options, in favor of longer-term options such as relocation of Ger households to apartment buildings), the government decided to go ahead with a program to replace existing stoves with clean, certified stoves.

Figure 0.1. Health benefit projections under various abatement scenarios in Ulaanbaatar

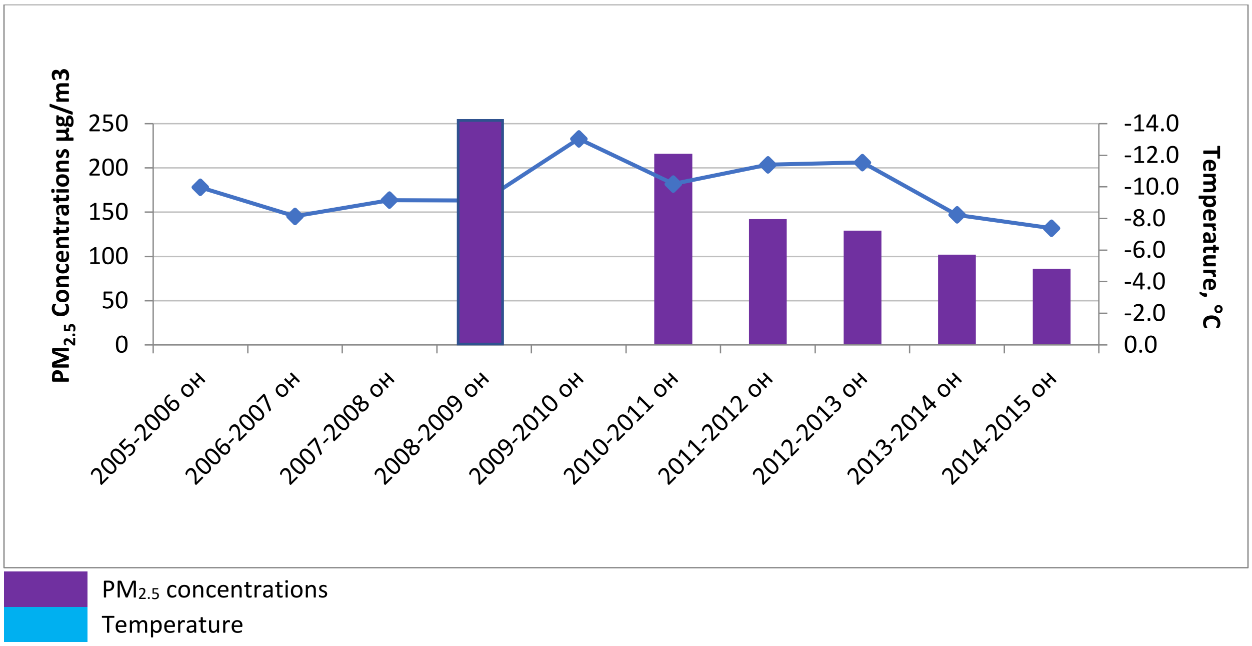


Source: World Bank 2011.

Results. Following completion of the full-scale AQM plan, the Ulaanbaatar clean air project supported by a loan from the World Bank implemented the immediate intervention of replacing stoves in Ger households with cleaner, more efficient models. Between 2011 and 2015, the Millennium Challenge Corporation, the World Bank, and the Government of Mongolia distributed more than 168,000 stoves representing 91 percent of the households that used coal-fueled stoves for cooking. Importantly, households received a subsidy that reduced the costs of replacing the stoves. During 2011–2013, the average subsidy was equivalent to 91 percent of the cost and was eventually reduced to 66 percent during 2014–2015. Subsequently, all 180,000 households were covered by the stove replacement program.

The implementation of the different measures to improve air quality—among which replacing stoves with cleaner, more efficient models was the most important immediate intervention—has resulted in clear improvements in air quality in Ulaanbaatar (Figure 5.2). Air pollution remains high, which underscores the need to broaden implementation of additional multisectoral interventions to reduce pollution emissions in the medium to long term.

Figure 0.2. $PM_{2.5}$ concentrations in Ulaanbaatar, 2005–2015



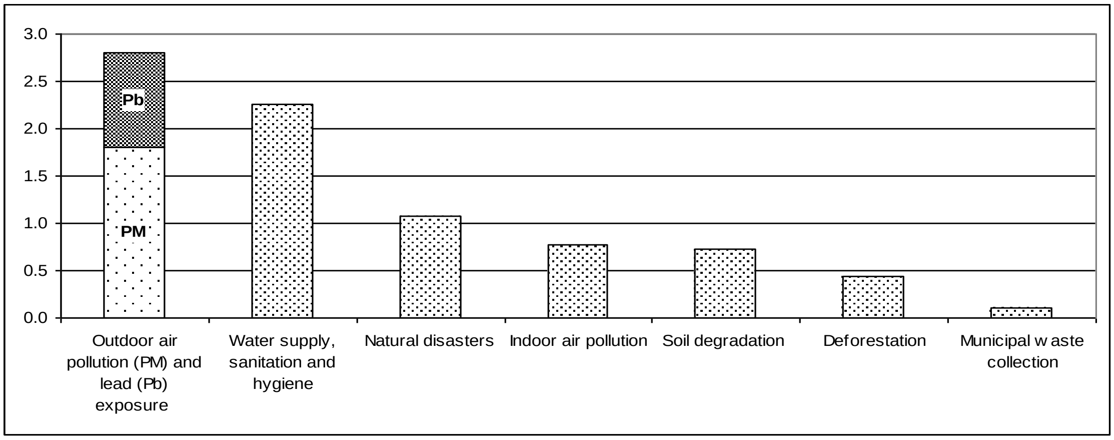
Source: Lodoysamba 2016.[21]

Reducing Air Pollution from Mobile Sources in Peru

Background. By the early 2000s, the Government of Peru had identified environmental degradation as a significant challenge for sustained economic growth. Upstream analytical work, specifically a Country Environmental Analysis (CEA) for Peru, was conducted with World Bank support. According to the CEA, the main categories of environmental degradation had an estimated cost of PEN 8.2 billion, an amount equivalent to 3.9 percent of Peru's GDP in 2003. Poor air quality in urban areas—from PM and ambient lead—accounted for the largest share of the health damage, which jointly amounted to about PEN 2.8 billion or 1.3 percent of GDP (Figure 5.3). AAP caused about 3,900 premature deaths annually and about 2,200 children suffered enough IQ loss to cause mild mental retardation associated with lead exposure. Air pollution was particularly severe in urban areas and industrial corridors such as Lima-Callao and Arequipa, the two largest cities in Peru. The CEA showed that poor people disproportionately carried the health burden of air pollution, with impacts on the poor more than three times higher than on non-poor people (Figure 5.4).

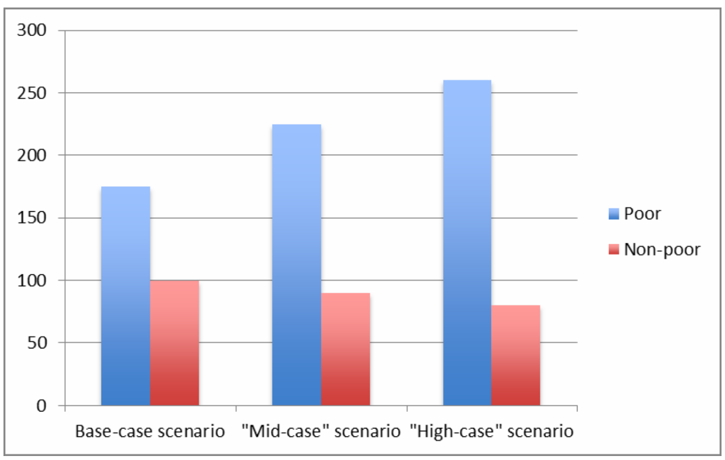
[21] Based on presentation to World Bank in December 2016 by Prof. S. Lodoysamba (retired), National University of Mongolia, Ulaanbaatar.

Figure 0.3. Annual cost of environmental degradation (billion soles)



Source: World Bank 2007.

Figure 0.4. Health impacts of AAP on poor and non-poor people in Lima-Callao

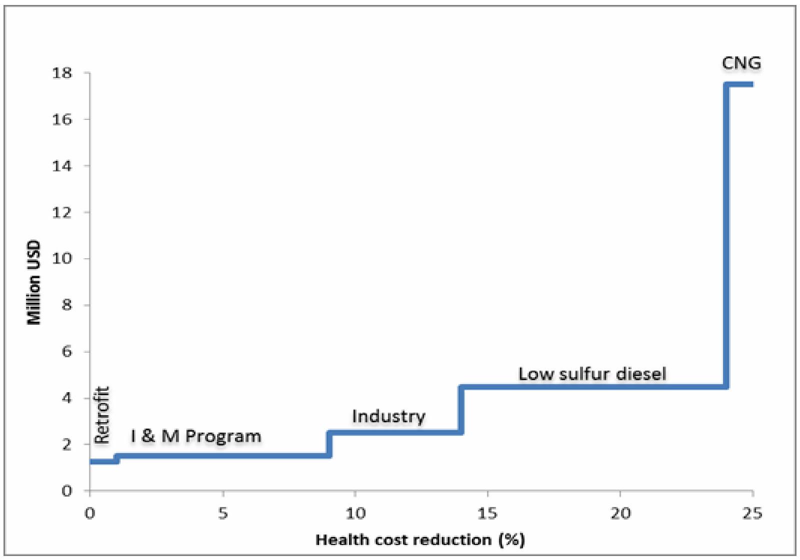


Source: Larsen and Strukova 2005.

Process. The CEA came from a process of dialogue between the Government of Peru, the World Bank, and country stakeholders, to build consensus around the analysis, and provided the basis for priority setting and decision making to inform the development of the government's program of policy actions to address air pollution. Within this context, 12 options for reducing AAP were examined: (a) introduction of low-sulfur diesel; (b) promotion of the use of gasoline-fueled cars instead of diesel through various tax incentives; (c) conversion of gasoline/diesel cars to natural gas, (d) conversion of some vehicles to ethanol or biofuel; (e) development of a new public transport system in Lima, the capital city; (f) provision of tax incentives to scrap older high-use cars (for example, taxis); (g) strengthening of inspection and maintenance programs; (h) retrofit of catalytic converters on cars and particle-control technology on diesel vehicles; (i) ban on importation of used cars for taxi use; (j) ban on use of diesel cars and/or two stroke engines as taxis; (k) implementation of various city planning interventions such as 'green traffic light waves' and bike lanes; and (l) introduction of measures to reduce industrial emissions. Some of the options were not considered in further detail beyond the initial examination due to various reasons. For example, the development of a new public transport system in Lima was not considered due to environmental reasons. Other policies had implications for welfare of transport users and/or affected other sectors, for example, increase in price of cars. Of the initial 12 options, 5 were ranked by comparing the health damage costs associated with a ton of emissions of PM, with the cost of a specific abatement option (Figure 5.5).

- Introduction of low-sulfur diesel
- Inspection and maintenance of programs
- Retrofit of particle-control technology
- Shift from low-sulfur diesel to compressed natural gas
- Reduction of industrial emissions

Figure 0.5. Marginal costs and benefits of interventions to reduce PM emissions in Peru



Source: ECON 2005.

Actions. Building on this analytical foundation, the government undertook a comprehensive and programmatic series of policy and institutional actions to address the severe costs of outdoor air pollution supported by a series of three World Bank loans totaling US$475 million over a two-year period. The government's program entailed tailored interventions to reduce emissions from mobile and industrial sources as well as interventions to strengthen the overall institutional framework for air quality and environmental management. Specific actions included strengthening the framework for air quality standards, emission levels, air quality monitoring and incorporating environmental sustainability principles in urban transport and industry, the main sectors responsible for driving air pollution in Peru.

A first set of actions taken by the government to reduce air pollution included, among others, (a) reduction of sulfur content in diesel; (b) implementation of a vehicle scrappage program to replace older, polluting vehicles with newer, natural gas vehicles; (c) enactment of a law requiring reduction of sulfur content in diesel; (d) issuance of a decree establishing requirements for diesel vehicles to access economic incentives; and (e) standards for the scrapping process. Subsequent actions by the government included the following:

(a) Actions to publish and disseminate air quality monitoring data in the highly polluted cities of Lima and La Oroya, a key center of metal smelting and refining.

(b) Issuance of a decree prohibiting supply of high-sulfur diesel (more than 50 parts per million sulfur content) in the metropolitan areas of Lima and Callao.

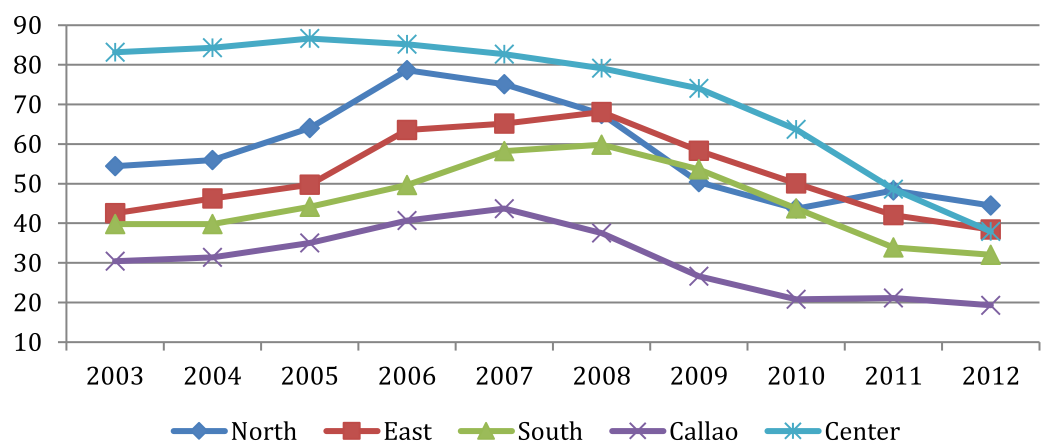
(c) Institutional measures to ensure continued funding of the vehicle conversion programs.

(d) Issuance of regulations to implement a vehicle inspection and maintenance program designed to remove highly polluting vehicles from the streets of Lima-Callao. Vehicles operating on public roads in this region were required to submit to a mandatory technical inspection for certifying the proper functioning and maintenance of motor vehicles and compliance with emission standards. As a result of these measures, approximately 1,000,000 vehicles are inspected yearly in Lima, and some 80,000 vehicles are inspected in the rest of the cities.

(e) Adoption of an investment plan for the modernization of Petróleos del Perú S.A.'s (PETROPERU) refinery that reduces the sulfur content in diesel.

Results. As a result of the comprehensive package of policy reforms and interventions adopted by the Government of Peru between 2009 and 2011, air quality improved markedly in the Lima-Callao region (Figure 5.6). Additional results included (a) inspection of 585,000 vehicles conducted compared to the baseline of 60,000 vehicles; (b) conversion of 83,000 vehicles to compressed natural gas; (c) all stations in Lima-Callao supplied with clean low-sulfur diesel by 2010, and 100 percent coverage was achieved in four additional major cities by 2012; and (d) number of service stations supplying natural gas in Lima rose from 0 to over 90.

Figure 0.6. Annual concentration of $PM_{2.5}$ in Lima-Callao, 2003–2012 (µg/m³; three-year average)



Source: Macizo and Sanchez, forthcoming.

Reducing Polluting Emissions through Multisectoral Interventions in China

Background: The Beijing-Tianjin-Hebei region (also known as Jing-Jin-Ji) has some of the most severe air pollution problems in China. Hebei Province is responsible for about 70 percent of emissions in the region. In 2012, the annual average concentration of ambient $PM_{2.5}$ was 112.9 µg/m³, compared with 88.3 µg/m³ in Beijing. Air pollution is caused by the high concentration of polluting industries, vehicles, and a large agricultural sector. Hebei is the largest iron and steel producer in China, accounting for about one-quarter of the national output. The power sector is almost entirely fueled by coal and nearly one-third of total installed capacity (15 out of 49 GW) was added since 2010. Hebei is also an important cement producer, having 21 plants with a total production capacity of 58.3 Mt per year, which is nearly 10 times the combined production capacity of Beijing and Tianjin of 6.3 Mt per year. In addition, the province accounts for 17 percent of national flat glass production. The agriculture sector is an important source of secondary PM pollution associated with NH_3 emissions from use of nitrogen-based fertilizers and livestock waste management.

As part of national efforts to improve air quality, the State Council of China issued the National Air Pollution Control Action Plan (the 'Ten Measures') in September 2013. According to the action plan, the Jing-Jin-Ji region was required to reduce concentrations of ambient $PM_{2.5}$ by 25 percent by 2017, compared to 2012. To achieve this goal, municipal, provincial, regional, and national governments implemented a comprehensive set of air quality improvement measures between 2013 and 2017 that targeted polluting emissions from coal, industrial sources, and mobile sources, as well as interventions to improve environmental management.

Process. In support of the government's program, the World Bank built on its long-term engagement on environmental, energy efficiency, and renewable energy topics in China, including analytical work and technical assistance, as well as established dialogue with different sectors across the government. To this end, the World Bank provided support to the Government of China to implement multisectoral interventions to address air pollution through two lending projects providing Program-for-Results (PforR) financing the Hebei Air Pollution Prevention and Control Project (US$500 million) and the Innovative Financing for Air Pollution Control for Jing-Jin-Ji Project (US$500 million) (World Bank 2016a, 2016b).The PforR financing supports the government's program and links disbursements to the achievement of results on the ground. Through the process of preparing these projects, the World Bank systematically reviewed the measures contained in the government's programs and plans, mobilized grant funding, and deployed international expertise and best practice across various relevant disciplines to provide technical assistance to the government for the identification, selection, and design of substantive actions that could be used as disbursement-linked indicators for the two projects. In addition, the process involved collaboration with think tanks, academia, and other development partners working on air quality issues in China.

Actions. The Hebei PforR Project aimed to reduce emission of specific air pollutants from industry, rural areas, and vehicles and improve air quality monitoring in Hebei. The Jing-Jin-Ji PforR Project aims to reduce air pollutants and carbon emissions through increasing energy efficiency and clean energy in Jing-Jin-Ji and neighboring regions.

Under the Hebei PforR, among the key actions taken to reduce polluting emissions are the following:

- **Continuous air emissions monitoring in industry and other point sources.** The province of Hebei is strengthening the system of continuous emissions monitoring (CEM) for air emissions and, to date, has broadening its implementation by Environmental Protection Bureaus (EPBs) at the provincial and prefecture level for enforcing emission standards. To date, 12 EPBs are implementing the CEM. In addition, the government strengthened implementation and expanded the coverage of the CEM system for industrial and other point sources of pollution. Currently, all state- and municipal-controlled enterprises have been integrated into the CEM system.

- **Installation of clean stoves in households.** The government strengthened technical standards for clean and efficient stoves and provided incentives for adoption of clean stoves that use processed biomass or coal briquettes by rural households. More than 1,200,000 clean stoves have been installed.

- **Adoption of environment-friendly fertilizers.** The actions aimed to support the adoption by farmers of environment-friendly, slow-release fertilizers that increase efficiency of nitrogen use based on soil testing and nutrient needs of crops. Nitrogen utilization efficiency has been increased in over 2 million ha of land planted with wheat.

- **Replacement of diesel buses with clean energy buses.** To reduce vehicular emissions, the government targeted urban public transport to accelerate the elimination of diesel buses, their replacement with battery and plug-in electric vehicles, and their proper disposal in accordance with national regulations. More than 2,400 diesel buses have been decommissioned and replaced with clean energy buses.

- **Establishment of air quality monitoring and warning systems and planning tools.** The government program supported (a) strengthening of the data collection system to have a comprehensive and complete source and composition inventory of the source structure of both primary and secondary PM and (b) development of a five-year plan for air pollution prevention and control, using modern ambient AQM planning tools to ensure cost-effectiveness and prioritization.

Under the Jing-Jin-Ji PforR, among the key actions taken to reduce polluting emissions are the following:

- **Reduction of coal consumption**. The national government sets coal consumption cutting goals, which for Jing-Jin-Ji meant reducing 13 million tons, 10 million tons, and 40 million tons for Beijing, Tianjin, and Hebei, respectively. Measures to achieve these goals included the replacement of coal-fired power generation, upgrading of industrial boilers, switching of thermal power sources, and control of raw coal burning.

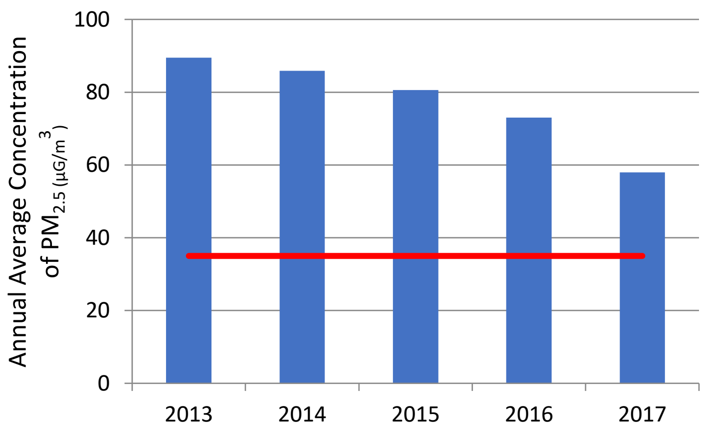
- **Desulfurization, denitrification, and dust elimination.** According to the action plan, by the end of 2015, Jing-Jin-Ji and its surrounding areas were expected to build or retrofit 59.7 GW of desulfurization capacity for coal-fired units, add or retrofit 16,000 m^2 of sinter machines for iron and steel manufacturers, add 110 GW of denitrification capacity for coal-fired power plants, and add or retrofit production capacity of 110 million tons of denitrification of cement clinker.

- **Ultralow emission control**. Beginning in 2015, China started the ultralow emission conversion of coal-fired power stations, which required that the pollutant emissions of these plants have the same emissions levels as those from combustion gas turbines. Nationwide, a total of 444 GW of coal power-generating units are being converted to ultra-low emission units.

- **Optimize industrial structure and eliminate disqualified enterprises.** The national government has revised regulations and requirements for high-energy consumption, high pollution, and resource-intensive industries. It also sets new targets for resource and energy conservation and pollutant emissions. Regions with severe pollution problems, such as Jing-Jin-Ji, can adopt even more stringent requirements. As a result, by the end of 2017, more than 60 million tons of steel production capacity was eliminated from the Jing-Jin-Ji region. In addition, coal-fired non-heat and power cogeneration units of less than 100 MW were completely phased out, while the elimination of units of less than 200 MW started.

Results. As a result of the adoption of comprehensive measures to improve air quality, $PM_{2.5}$ concentration in the Jing-Jin-Ji region declined by an average of 39 percent between 2013 and 2017. Air quality improvements have been especially significant in Beijing, where the annual average concentration of $PM_{2.5}$ fell from 89.5 μg/m^3 in 2013 to 58 μg/m^3 in 2017 (Figure 5.7). However, $PM_{2.5}$ concentration in the city still substantively exceeds China's national standard. In addition, the share of renewable energy in Beijing increased from about 3 percent in 2010 to 7.6 percent in 2017. The reductions in coal consumption (72.3 million tons) for the region were also accompanied by significant reductions in CO_2 emissions (105.31 million tons).

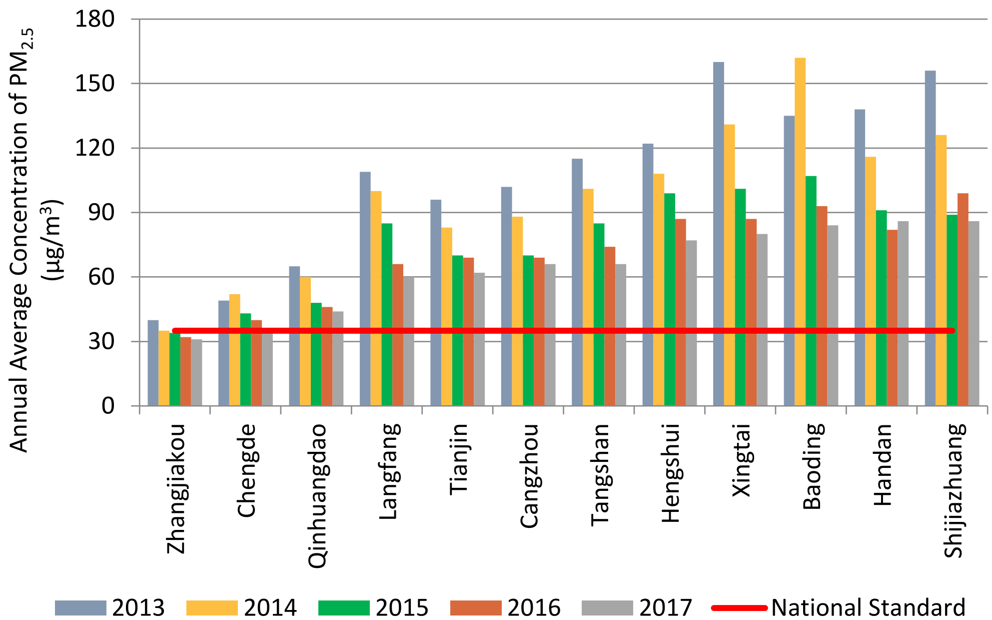
Figure 0.7. Annual average concentration of $PM_{2.5}$ in Beijing from 2013 to 2017



Source: ICCS 2018.

In most cities surrounding Beijing, $PM_{2.5}$ concentrations have been falling constantly, but only two cities (Zhangjiakou and Chengde) met the national standard in 2017. Only in one city (Handan City in Hebei province) pollution increased in 2017 compared to the previous year (Figure 5.8). Improving air quality requires sustained commitment to implement comprehensive interventions that result in emissions reductions in the short, medium, and long term, as underscored by the fact that cities continue to exceed China's air quality standards.

Figure 0.8. Annual average concentration of $PM_{2.5}$ for 12 surrounding cities of Beijing in Jing-Jin-Ji region, 2013–2017



Source: ICCS 2018.

5.3 Conclusions and Lessons Learned

The examples presented in this chapter illustrate the complexity of air pollution and the need for integrated approaches and solutions that are appropriate to the specific city (or urban area) context. A single sector or institution is unable to solely undertake the extensive work that is involved in effectively addressing air pollution. The examples discussed show how the World Bank has been able to play an integrative role by bringing together and fostering dialogue between, and engagement of, various national and international stakeholders, including different sectors of the economy, think tanks, academia, other development partners, and supporting crucial analytical work to inform investments and policy and institutional actions for AQM.

The following paragraphs provide some additional salient conclusions from the Mongolia, Peru, and China examples and lessons learned from their experiences, which may find application in North Macedonia as the government advances in its efforts to tackle air pollution.

The design and implementation of economically effective interventions to successfully reduce air pollution must be underpinned by a solid and rigorous foundation of analytical work to inform the identification and selection of priorities and interventions. As may be seen from the Peru and Mongolia examples, such analytical work also provides a platform around which various relevant stakeholders, including, among others, the government (across different sectors and different levels of government), think tanks, academia, private sector, and donor agencies, can engage and come to informed conclusions about possible interventions and implementation of an appropriate air pollution reduction program.

Interventions for abating air pollution from different sectors are broadly well known. The selection of specific interventions in a given context should, however, be informed by analysis of the benefits and costs of implementing the respective intervention. Benefit-cost analysis (BCA) compares the health benefits of an intervention, that is, avoided cost of premature mortality and morbidity due to air pollution, to the cost of implementing the intervention. BCA allows decision makers to rank and prioritize alternative interventions and select interventions that have a benefit-cost ratio (BCR) greater than unity (BCR > 1). This exercise should also consider existing policy and operational constraints related to performance of existing infrastructure and institutional capacity that could foreclose or limit the implementation of certain air pollution reduction interventions.

Conducting in-depth analytical work is often time intensive and could span several years, as in the case of Mongolia, requiring adequate budgetary resources. It is recognized that in many contexts, the severity of air pollution and its health impacts as well as public pressure on government and city officials to act may call for interventions in the immediate to short term to reduce air pollution. In such cases, a city could consider applying reasonable interventions that would help alleviate air pollution in the short term such as restricting pollution from known stationary sources or traffic restrictions. However, such short-term actions are unlikely to be able to effectively reduce air pollution in the long term, in particular where air pollution sources are many and varied. They should not replace a strategic and integrated approach informed by rigorous analytical work and engagement of various relevant stakeholders across different sectors (for example, environment, energy, transport, economy, agriculture); development partners; academia; and others to inform design and implementation of economically effective interventions for sustained or long-term air pollution reduction.

In addition to technical interventions, for example, implementation of a clean stove program or installation of emission reduction technologies in industrial facilities such as in the China example, efforts to reduce air pollution should incorporate the use of a menu of instruments, including command-and-control, market-based, and economic instruments such as in the example of Peru where a law was enacted to reduce sulfur content of diesel; a regulation was issued to implement vehicle inspection and maintenance program (command-and-control); and economic incentives were used for replacement of diesel vehicles with cleaner vehicles. Setting air quality targets, as shown in the China example, is also an important aspect of improving air quality, and government's commitment to achieving targets is required, including through supporting requisite analytical work for developing realistic and achievable targets.

Air pollution disproportionately affects people of lower economic status compared to non-poor people. It is important that policies to reduce air pollution consider distributional and social impacts on affected populations in different income groups. Poverty and social impact analysis could be used to understand distributional impacts of policies to reduce air pollution to ensure that poor and vulnerable groups of people do not disproportionately carry the burden associated with implementation of such policies. For example, poorer people are more likely to drive older, polluting vehicles. Poor people are also more likely to burn cheap and highly polluting fuels for domestic purposes. Therefore, policies that prohibit the use of old, polluting vehicle in favor of newer, clean vehicles could incorporate financial or other suitable incentives for poorer people to comply with the policies. Similarly, programs to promote replacement of polluting stoves with clean, efficient stoves should incorporate incentives that will help low-income households' transition to burning cleaner fuels.

Some ongoing efforts by various development partners to support North Macedonia's efforts to reduce air pollution were highlighted in the previous chapter. Moving forward, stocktaking of the outcomes of these efforts and identification of opportunities where investments and policy and institutional actions can augment impacts on air quality supported by appropriate financing mechanisms could be useful in informing the government’s next steps. Stocktaking and identification of opportunities and financing mechanisms should be coordinated among donors and conducted in collaboration with the government. Government commitment to undergird and build upon the outcomes of ongoing donor support by ensuring sustained and adequate human and budgetary support will be crucial for sustained impact in reducing air pollution.

Chapter 6. Recommendations

The recommendations of this report are summarized in Table 6.1.

Table 0.1. Summary of recommendations to strengthen AQM in North Macedonia

Recommendation	Time Frame
Legal and Policy Framework	
Strengthen the legal framework, focusing on specific instruments that reduce pollution from mobile sources, large stationary sources, and household heating.	Short to medium term
Strengthen the legal framework by adopting and implementing diverse air pollution management instruments, including economic and market-based instruments.	Medium term
Introduce standard for daily average ambient $PM_{2.5}$ concentration.	Short to medium term
Air Quality, Emissions and Health Data and Analysis	
Strengthen the air quality monitoring network to provide reliable time series data on pollutants notably $PM_{2.5}$.	Short term
Expand air quality monitoring to include chemical constituents and species of PM such as elemental carbon, organic carbon, sulfates associated with combustion processes; $PM_{2.5}$ precursors including SO_2, NO_x, NH_3, and NMVOC; BC; and heavy metals such as lead.	Short to medium term
Conduct baseline measurement exercises: (a) PAH measurements in one urban location in each zone and agglomeration to define further measurement needs and potential interventions and (b) one-year campaigns in selected hotspot or industrial locations to estimate ambient concentrations of heavy metals.	Short to medium term
Improve meteorological observational data outside of Skopje, background monitoring data, and a comprehensive inventory of pollutants to improve dispersion modeling.	Medium to long term
Strengthen inventories for residential and transport sectors including (a) transport - validate data consistency, address all pollutants including BC, strengthen inventory development methods to capture local context and (b) residential - improve fuelwood statistics, analyze typical fuelwood quality, and analyze information on combustion technology in use in the country.	Short to medium term
Strengthen capacity to conduct health risk assessment.	Short to medium term
Strengthen health statistics to allow estimation of AAP-related mortality by cause	
Improve site-specific collection and reporting of morbidity data attributable to AAP for specific diseases and age groups.	
Reducing Pollution from Different Sectors/Sources	
Residential. (a) Pilot substitute traditional stoves with more efficient ones and build on lessons learned and experience to date to develop a large-scale program; (b) put in place targeted financial incentives to help poor households adopt clean, efficient, stoves; and (c) implement public awareness campaign to promote stove replacements.	Short to medium term
Mobile sources. (a) Promote lower sulfur content fuels; (b) implement vehicle scrappage programs to replace older, polluting vehicles with newer, less polluting vehicles; (c) promote conversion of vehicles through technological measures and financial incentives; (d) strengthen vehicle inspection and maintenance programs; and (e) strengthen enforcement of measures to reduce importation of older, polluting vehicles.	Medium to long term
Stationary sources. (a) Strengthen enforcement to ensure that large polluters develop and adopt plans to gradually reduce their emissions and comply with environmental standards, which should be continued and strengthened; (b) financial incentives for small industrial facilities to undertake air pollution control measures; (c) use of sanctions that are clear and commensurate with the damage caused by polluters that exceed their approved emission levels; and (d) incorporate $PM_{2.5}$ in ongoing revision of National	Short to medium term

Recommendation	Time Frame
Program for Gradual Reduction of the Quantities of Emissions of Certain Pollutants for 2016–2030.	
Transboundary sources. Establish, together with neighboring countries, a technical knowledge platform on transboundary pollution	Short to medium term
Organizational Framework	
Adequately staff organizations with responsibilities for AQM	Short term
Revise the current organizational structure to incorporate units that are specifically dedicated to developing, implementing, monitoring, and evaluating air quality laws, policies, programs, and projects.	Short term
Develop an institutional structure to ensure ongoing evaluations of AQM policies and interventions.	Medium term
Public Participation	
Establish a multistakeholder air quality advisory board to periodically discuss the development, implementation, and evaluation of actions to improve air quality	Short term
Support public interest advocacy through legal associations, establishing environmental law clinics at universities, and providing training and disseminating specific materials for targeted audiences	Medium term
Enforcement	
Expand the number of inspectors and provide them with training and resources to conduct field investigations	Short term
Strengthen enforcement by clarifying sanctions for noncompliance, increasing fines, and expanding the range of sanctions	Medium term

References

Abbey, D., M. D. Lebowitz, P. K. Mills, F. F. Petersen, W. L. Beeson, and R. J. Burchette. 1995. "Long-Term Ambient Concentrations of Particulates and Oxidants and Development of Chronic Disease in a Cohort of Nonsmoking California Residents." *Inhalation Toxicology* 7:19–34.

Ahmed, K., and E. Sanchez-Triana. 2008. *Strategic Environmental Assessment for Policies: An Instrument for Good Governance*. Washington, DC: World Bank.

Amann, M., I. Bertok, J. Borken-Kleefeld, J. Cofala, C. Heyes, L. Höglund-Isaksson, Z. Klimont, et al. 2011. "Cost-effective Control of Air Quality and Greenhouse Gases in Europe: Modeling and Policy Applications." *Environmental Modelling & Software* 26:1489–1501.

Anttila, P., A. Stefanovska, A. Nestorovska-Krsteska, l. Grozdanovski, I. Atanasov, N. Golubov, P. Ristovski, et al. 2016. "Characterisation of Extreme Air Pollution Episodes in an Urban Valley in the Balkan Peninsula." *Air Quality, Atmosphere & Health* 9 (2): 129–141.

AP (Associated Press). 2018. "Macedonia Takes Emergency Measures against Air Pollution." January 8. https://www.businessinsider.com/ap-macedonia-takes-emergency-measures-against-air-pollution-2018-1.

Awe, Y., J. Nygard, S. Larssen, H. Lee, H. Dulal, and R. Kanakia. 2015. "Clean Air and Healthy Lungs: Enhancing the World Bank's Approach to Air Quality Management." Environment and Natural Resources Global Practice Discussion Paper No. 3, World Bank, Washington, DC.

Blair, H. 2008. "Building and Reinforcing Social Accountability for Improved Environmental Governance." In *Strategic Environmental Assessment for Policies: An Instrument for Good Governance*, edited by K. Ahmed and E. Sanchez-Triana, 127–57. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/6461.

Burnett, R., H. Chen, M. Szyszkowicz, N. Fann, B. Hubbell, C. A. Pope, J. S. Apte, et al. 2018. "Global Estimates of Mortality Associated with Long-term Exposure to outdoor fine particulate matter." *Proc Natl Acad Sci U S A* 115 (38): 9592–9597.

Burnett, R. T., C. A. Pope III, M. Ezzati, C. Olives, S. S. Lim, S. Mehta, H. H. Shin, et al. 2014. "An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure." *Environmental Health Perspectives* 122 (4): 397.

CEC (Commission of the European Communities). 2001. *Communication from The Commission. The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality*. Brussels: CEC. http://ec.europa.eu/environment/archives/cafe/general/keydocs.htm.

Dimovska, M., and D. Gjorgjev. 2018. "Assessing Health Impact of Air Pollution in Macedonian Cities." *Biomed J Sci and Tech Res* 10 (1). doi:10.26717/BJSTR.2018.10.001887.

EC (European Commission). 2001. "Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the Limitation of Emissions of Certain Pollutants into the Air from Large Combustion Plants."

———. 2018. *The Former Yugoslav Republic of Macedonia 2018 Report*. Commission Staff Working Document. Accompanying the document: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 2018 Communication on EU Enlargement Policy. Strasbourg, 17.4.2018 SWD (2018) 154 final.

ECON Analysis. 2005. "Urban Air Pollution Control in Peru." Unpublished background report submitted to the World Bank.

Energy Community. 2005. "Treaty Establishing Energy Community."

EU (European Union). 2008. "Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe." http://data.europa.eu/eli/dir/2008/50/oj.

FMI (Finnish Meteorological Institute) and MEPP (Ministry of Environment and Physical Planning). 2017. *Further Strengthening the Capacities for Effective Implementation of the Acquis in the Field of Air Quality.* Final Report. Twinning Project.

Gallego, F. J. 2010. "A Population Density Grid of the European Union." *Population and Environment* 31 (6): 460–73. https://doi.org/10.1007/s11111-010-0108-y.

GBD 2016. Disease and Injury Incidence and Prevalence Collaborators. 2017. "Global, Regional, and National Incidence, Prevalence, and Years Lived with Disability for 328 Diseases and Injuries for 195 countries, 1990–2016: A Systematic Analysis for the Global Burden of Disease Study 2016." *Lancet* 390 (10100): 1211–1259. https://doi.org/10.1016/S0140-6736(17)32154-2.

GONM (Government of North Macedonia). 2011. "Law on Ambient Air Quality." Official Gazette No. 67/04, 92/07, 35/10, 47/11, 59/12, 163/13, 10/15,39/16 and 99/18.

Grncarovska, Teodora O. 2014. "Implementation Plan for Transferring EU Legislation in the Field of Climate Change." Former Yugoslav Republic of Macedonia, Skopje. http://www.locsee.eu/uploads/documents/plans/MK_Implementation%20Plan_final.pdf.

HEAL (Health and Environmental Alliance). 2016. *The Unpaid Health Bill: How Power Plants in the Western Balkans Make Us Sick.* http://env-health.org/IMG/pdf/factsheet_eu_and_western_balkan_en_lr.pdf.

Héroux, M., H. R. Anderson, R. Atkinson, B. Brunekreef, A. Cohen, F. Forastiere, F. Hurley, et al. 2015. "Quantifying the Health Impacts of Ambient Air Pollutants: Recommendations of a WHO/Europe Project." *Int J Public Health* 60:619–627. doi:10.1007/s00038-015-0690-y.

ICCS (Innovation Center for Clean-air Solutions). 2018. "Assessment of Jing-Jin-Ji Air Quality Improvement (2013–2017)." Beijing.

Interreg. 2018. "European Territorial Cooperation (Interreg): Project Beneficiaries: Ministry of Environment and Physical Planning." http://www.ipa-cbc-programme.eu/project-partner/384/.

Kiesewetter, G., and Markus Amann. 2014. "Urban $PM_{2.5}$ Levels under the EU Clean Air Policy Package." International Institute for Applied Systems Analysis.

Kiesewetter, G., J. Borken-Kleefeld, W. Schöpp, C. Heyes, P. Thunis, B. Bessagnet, E. Terrenoire, et al. 2015a. "Modeling Street Level PM10 Concentrations across Europe: Source Apportionment and Possible Futures." *Atmos. Chem. Phys* 15 (3): 1539–53. https://doi.org/10.5194/acp-15-1539-2015.

Kiesewetter, G., W. Schoepp, C. Heyes, and M. Amann. 2015b. "Modeling $PM_{2.5}$ Impact Indicators in Europe: Health Effects and Legal Compliance." *Environmental Modelling & Software* 74:201–211. https://doi.org/10.1016/j.envsoft.2015.02.022.

Landrigan, P., R. Fuller, N. J R Acosta, O. Adeyi, R. Arnold, N. Basu, A. B. Baldé, et al. 2017. "The Lancet Commission on Pollution and Health." Published online October 19, 2017. http://dx.doi.org/10.1016/S0140-6736(17)32345-0.

Lanzani, G. 2010. *Relevant Stakeholders and Their Role in Implementing the Ambient Air Quality Legislation.* Twinning Technical Report No. 2/2010. Assessment including recommendations. Component 2: Strengthening the administrative capacity to implement the ambient air quality legislation.

Larsen, B., and E. Strukova. 2005. *Peru: Cost of Environmental Damage: An Analysis of Environmental Health and Natural Resources*. Background report for the Peru Country Environmental Analysis. Washington, DC: World Bank.

Lindhjem, H., S. Narvud, N. A. Braathen, and V. Biausque. 2011. "Valuing Mortality Risk Reductions from Environmental, Transport, And Health Policies: A Global Meta-Analysis of Stated Preference Studies." *Risk Analysis* 31 (9): 1381–1407.

Lodoysamba, S. 2016. "Presentation to the World Bank in December 2016." World Bank.

Macizo, G., and S. Sanchez. Forthcoming. "Lima and Callao Case Study." In *Air Quality Management in Latin American Cities*, edited by E. Sanchez-Triana and S. Sanchez. Washington, DC: World Bank.

Mallada, M. J., C. Braams, C. Seoánez, and I. Bergareche. 2015. "Proposals for the Improvement of the Environmental Inspection System. Programme for Improvement of Administrative Capacities of Environmental Inspection Authorities." Project MK-10-IB-EN-01. EU Twinning Project "Strengthening the administrative capacities at central and local level of implementation and enforcement of the environmental acquis." http://www.sei.gov.mk/projects_page_en.asp?ID=6.

Martinez, G. S., J. V. Spadaro, D. Chapizanis, V. Kendrovski, M. Kochubovski, and P. Mudu. 2018. "Health Impacts and Economic Costs of Air Pollution in the Metropolitan Area of Skopje." *Int. J. Environ. Res. Public Health* 15:66. doi:10.3390/ijerph15040626.

MEPP (Ministry of Environment and Physical Planning). 2017. *Macedonian Air Quality Assessment Report for the Period 2005–2015.* Skopje: MEPP. http://air.moepp.gov.mk/wp-content/uploads/2017/07/AirQualityReport_EN.pdf.

———. 2018. *Republic of Macedonia Informative Inventory Report 1990–2016. Under the Convention on Long-Range Transboundary Air Pollution (CLRTAP).* Skopje: MEPP. http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting/2018_submissions/.

MEPP and EEA. 2018. *SEIS Country Report Republic of Macedonia.* Final Version June 2018. http://www.moepp.gov.mk/wp-content/uploads/2017/07/SEIS_Country-Report_-Republic-of-Macedonia_2018_Final.pdf.

MFA (Ministry of Foreign Affairs of the Netherlands). 2009. "Evaluation Policy and Guidelines for Evaluations." Policy and Operations Evaluation Department.

Ministry of Environment and Physical Planning, Macedonian Information Center, and Finnish Meteorological Institute. 2017. *Macedonian Air Quality Assessment Report for the Period 2005–2015*. Skopje.

Narain, U., and C. Sall. 2016. "Methodology for Valuing the Health Impacts of Air Pollution: Discussion of Challenges and Proposed Solutions." World Bank, Washington DC.

OECD (Organisation for Economic Co-operation and Development). 2010. "Evaluation in Development Agencies, Better Aid." OECD Publishing. http://dx.doi.org/10.1787/9789264094857-en.

Ostro, B. 1994. "Estimating the Health Effects of Air Pollution: A Method with an Application to Jakarta." Policy Research Working Paper, World Bank, Washington, DC.

———. 2004. "Outdoor Air Pollution: Assessing the Environmental Burden of Disease at National and Local Levels." Environmental Burden of Disease Series No. 5, WHO, Geneva.

Ostro, B., J. V. Spadaro, S. Gumy, P. Mudu, Y. Awe, F. Forastiere, and A. Peters. 2018. "Assessing the Recent Estimates of the Global Burden of Disease for Ambient Air Pollution: Methodological Changes and Implications for Low- and Middle-Income Countries." *Environmental Research* 166:713–725.

Pokrovac Patekar, A., W. Douma, and S. van der Velde. 2015. "Legal Assessment of Existing Administrative Capacities for Enforcement of Environmental Legislation at Central and Local Levels. New Law for Inspection on Environment." Project MK-10-IB-EN-01. Activity no. 2.1. EU Twinning Project "Strengthening the administrative capacities at central and local level of implementation and enforcement of the environmental acquis." http://www.sei.gov.mk/projects_page_en.asp?ID=6.

Pope, C. A., III, R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito, and G. D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution." *JAMA* 287 (9): 1132–1141.

Sanchez-Triana, Ernesto, Santiago Enriquez, Javaid Afzal, Akiko Nakagawa, and Asif Shuja Khan. 2014. *Cleaning Pakistan's Air. Policy Options to Address the Cost of Outdoor Air Pollution.* Directions in Development. Washington, DC: World Bank. http://hdl.handle.net/10986/18887.

Simpson, D., A. Benedictow, H. Berge, R. Bergström, L. D. Emberson, H. Fagerli, C. R. Flechard, et al. 2012. "The EMEP MSC-W Chemical Transport Model – Technical Description." *Atmos. Chem. Phys* 12 (16): 7825–65. https://doi.org/10.5194/acp-12-7825-2012.

Stefanovska, A. 2018. "Air Quality Management in the Republic of Macedonia." Presentation delivered on March 6 in Skopje.

Twinning Project Newsletter. 2015. "Further Strengthening the Capacities for Effective Implementation of the Acquis in the Field of Air Quality." No. 1, December.

van Donkelaar, A., R. Martin, M. Brauer, and B. Boys. 2015. "Use of Satellite Observations for Long-Term Exposure Assessment of Global Concentrations of Fine Particulate Matter." *Environ Health Perspect* 123 (2): 135–143. doi:10.1289/ehp.1408646.

World Bank. 2007. *Republic of Peru - Environmental Sustainability: A Key to Poverty Reduction in Peru*. Washington, DC: World Bank.

———. 2011. *Air Quality Analysis of Ulaanbaatar: Improving Air Quality to Reduce Health Impacts. Discussion Papers Sustainable Development – East Asia and Pacific Region*. Washington, DC: World Bank

———. 2012. *Integrated Air Pollution Management in China: Developing Particulate Matter Control.* Washington, DC: World Bank.

———. 2014. *FYR Macedonia Green Growth Country Assessment*. Washington, DC: World Bank.

———. 2017. *Biomass-Based Heating in the Western Balkans – A Roadmap for Sustainable Development (Final Report).* Washington, DC: International Bank for Reconstruction and Development/World Bank.

———. 2018. "World Development Indicators."

World Bank, and IHME. 2016. *The Cost of Air Pollution: Strengthening the Economic Case for Action*. Washington, DC: World Bank.

WHO (World Health Organization). 2006. *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide*. Geneva: WHO.

Xu, G., L. Jiao, B. Zhang, S. Zhao, M. Yuan, Y. Gu, J. Liu, et al. 2017. "Spatial and Temporal Variability of the $PM_{2.5}/PM_{10}$ Ratio in Wuhan, Central China." *Aerosol and Air Quality Research* 17:741–751.

Annex A. Overview of Major Air Pollutants

Table A.1. Major air pollutants

Pollutant	Full name	Description
PM	Particulate matter	Airborne PM includes a wide range of particle sizes and different chemical constituents. When inhaled, PM can cause inflammation and worsen heart and lung diseases, which can lead to premature death. Fine and ultrafine PM are particularly harmful, as they tend to penetrate deepest into the lungs due to their smaller size. $PM_{2.5}$, a known carcinogen, is most documented for its adverse health impacts. Primary particles are emitted directly from a source, such as combustion of fossil fuels, especially coal and diesel, in vehicles and industry, domestic heating and cooking, construction, and burning of waste crop residues. Secondary particles, on the other hand, are formed in complicated atmospheric reactions among gases that are emitted from power plants, industries, agricultural practices, and automobiles. Key precursors of secondary PM are SO_2, NO_x, and NH_3.
SO_2	Sulfur dioxide	SO_2 is a colorless gas with a sharp odor, produced by combustion of fossil fuels and the industrial refining of ores that contain sulfur. Its oxidized form, also known as sulfate, is a particulate. SO_2 can affect the respiratory system and irritate the eyes.
NO_x	Nitrogen oxides	Major emission sources of NO_x include automobiles and combustion in power plant boilers and industrial activities. NO_2 is a gas which, at higher concentrations, can irritate the airways of the lungs, increasing the symptoms of those suffering from lung diseases. It also contributes to the formation of ground-level O_3 and fine particle pollution. It is chemically related to nitric oxide (NO) and together NO_2 and NO are known as NO_x.
O_3	Ozone	O_3 is a gas which can adversely affect the respiratory system even at relatively low levels. O_3 is the most complex of the legislated pollutants, and therefore the hardest to reduce, as it is not emitted directly from any source. Instead it is formed in the atmosphere by photochemical reactions in the presence of sunlight and precursor pollutants, such as NO_X and VOCs. It is also destroyed by reactions with NO_2. Tropospheric (ground level) O_3 is a contributor to global climate change.
Toxic air pollutants	Toxic air pollutants	The air toxics are a cluster of pollutants that are implicated in higher cancer rates and higher rates of immune or neurological damage, genetic defects, and/or heart and respiratory issues. Members of this group include benzene, PAHs; polychlorinated biphenyls; and VOCs, dioxins, and furans, which are products of incomplete combustion of carbon-based fuels. Air toxics can come from mobile sources, stationary sources, or some indoor sources, such as certain solvents or building materials. Their damage is directly correlated to overall levels in the body. They can accumulate in the body's fatty tissues and can be passed to infants through breast feeding. One member of this group is the carcinogenic benzo[a]pyrene (B[a]P), which is a PAH. Major sources of PAHs in ambient air include residential and commercial heating with wood, coal, or other biomasses; motor vehicle exhaust (especially from diesel engines); industrial emissions; and forest fires.
Heavy metals	Heavy metals	Human populations can suffer morbidity and mortality from certain heavy metals that are sometimes found in the air. Lead is the most important heavy metal for health globally, given its widespread distribution at concentrations that may damage health. Prolonged exposure to lead is linked to neurological and developmental damage in children. In addition to lead, this group includes arsenic, cadmium, manganese, mercury, and nickel. Arsenic, a carcinogen, is emitted from both natural and anthropogenic sources. Anthropogenic sources are primarily associated with the mining and smelting of base metals, fuel combustion (of waste and low-grade coal), and the use of arsenic-based pesticides.

Annex B. Calculation of the Health Burden Attributed to Ambient Air Pollution based on GBD 2016

Risk of Mortality Attributed to $PM_{2.5}$

The strongest causal associations are seen between $PM_{2.5}$ pollution and cardiovascular and pulmonary disease. Particles of smaller size reach the lower respiratory tract and thus have greater potential for causing the lungs and heart diseases. As the 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.

Hence, epidemiological studies (Landrigan et al. 2017) established that long-term exposure to current ambient PM concentrations lead to a marked reduction in life expectancy. The increase of cardiopulmonary (IHD, stroke, COPD), lung cancer mortality in population over 30 years of age, and LRI mortality in all population are the main reasons for the reduction in life expectancy.

As the WHO project 'Health risks of air pollution in Europe' advised for the use in Europe and based on the established methodology in the World Bank (Héroux et al. 2015; World Bank and IHME 2016), this report estimates risk of long-term mortality associated with air pollution as PAFs of the following diseases (disease codes from GBD 2016 are provided in square brackets):

1. IHD (population above 30 years of age) - [B.2.2]
2. Stroke (population above 30 years of age) - [B.2.3]
3. Lung cancer (population above 30 years of age) - [B.1.11]
4. COPD (population above 30 years of age) - [B.3.1]
5. LRI (all ages) - [A2.2]

This approach allows estimating age-specific mortality by cause attributed to AAP for the most affected population groups. Risks associated with exposure to $PM_{2.5}$ are estimated using methods described in Burnett et al. (2014) that assume supralinear and age-specific (for IHD and stroke) function of relative risk attributed to air pollution. Relative risk estimates for all five diseases in question are consistent with the GBD 2016 study (GBD 2016 Disease and Injury Incidence and Prevalence Collaborators 2017).

PAF translates the annual mortality for LRI, COPD, lung cancer, stroke, and IHD into the health burden attributed to $PM_{2.5}$ exposure. Using the established relative risk functions, the PAF by disease (LRI, COPD, lung cancer, stroke, and IHD) from $PM_{2.5}$ exposure is calculated using the following formula, for each age group and for each disease outcome *k*:

$$PAF_{kl} = \frac{\sum_{i=1}^{n} P_i(RR-1)}{\sum_{i=1}^{n} P_i\,(RR-1)+1},$$

where *i* is the level of $PM_{2.5}$ in µg/m^3, P_i is the percentage of the population exposed to that level of air pollution, and *RR* is the relative risk of mortality due to $PM_{2.5}$ exposure.

Then the disease burden (B) in terms of annual cases of disease outcomes due to $PM_{2.5}$ exposure is estimated by

$$B = \sum_{k=1}^{t}\sum_{l=1}^{s} D_{kl} PAF_{kl,}$$

where D_{kl} is the total annual number of cases of disease, *k*, in age group, *l*, and PAF_{kl} is the attributable fraction of these cases of disease, *k*, in age group, *l*, due to $PM_{2.5}$ exposure. Additional information on the applicable functions can be found in the following sources: World Bank and IHME (2016), Ostro et al. (2018), and GBD 2016 Disease and Injury Incidence and Prevalence Collaborators (2017).

Annex C. Valuation of Mortality and Morbidity Attributed to Ambient Air Pollution

Welfare Approach for Valuation of Mortality Cases

The VSL is estimated for North Macedonia to monetize risk of mortality cases associated with air pollution. The range in cost is due to the range of baseline VSL in Organisation for Economic Co-operation and Development (OECD), as first suggested in the OECD study (Lindhjem et al. 2011) and updated in (Narain and Sall 2016), and different elasticity of willingness to pay to avoid health risk. The baseline VSL is selected as the mean for high and median for low of VSL estimated in the OECD studies (Narain and Sall 2016).

For transfers between countries, VSL should be adjusted with the difference in GDP per capita in purchase power parity coefficient (PPP) to the power of an income elasticity of VSL of 1-1.4 (Narain and Sall 2016), for low- and middle-income countries. Application of PPP for VSL estimation requires adjustment of the estimated VSL back to market prices.

VSL estimates can be transferred from OECD countries to North Macedonia using benefits transfer method, which posits that

$$VSL_{K\ in\ PPP} = VSL_{OECD\ in\ PPP} \left(\frac{Y_{K\ in\ PPP}}{Y_{OECD\ in\ PPP}} \right)^{\varepsilon},$$

$$VSL_K = \frac{VSL_{K\ in\ PPP}}{PPP},$$

where

$VSL_{K\ in\ PPP}$	=	VSL in North Macedonia in PPP terms (2016)
$VSL_{OECD\ in\ PPP}$	=	VSL in OECD countries in PPP terms (2011)
$Y_{K\ in\ PPP}$	=	Per capita GDP in North Macedonia in PPP terms (2016)
$Y_{OECD\ in\ PPP}$	=	Per capita GDP in OECD in PPP terms (2011)
PPP	=	Purchasing power parity for North Macedonia (2016)
ε	=	Income elasticity of VSL

Table C.1 presents the derivation of a range of VSL for North Macedonia from low end (US$0.36 million) and high end (US$0.58 million) VSL estimates in OECD countries (Narain and Sall 2016), using the abovementioned formula. This range of adjusted VSL is used in welfare-based Cost of Environmental Degradation (CoED) estimates in this report.

Table 0.1. Benefit transfer of VSL for North Macedonia

	Low	High
Average VSL estimates from OECD (US$, millions)	3.6	4.1
Country's GDP (US$, billions) in 2016	10.9	10.9
Country's GDP PPP (US$, billions) in 2016	31.1	31.1
Population (millions) in 2016	2.07	2.07

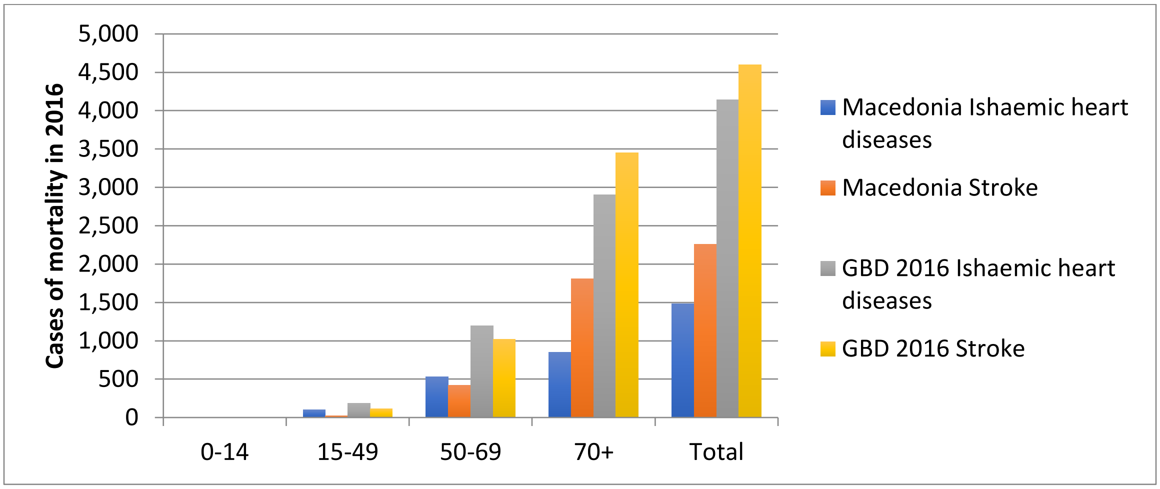
	Low	High
GDP per capita (PPP US$) in 2016	15,010	15,010
Average GDP/capita differential	0.41	0.41
Income elasticity of VSL	1.40	1.00
PPP	2.85	2.85
VSL transferred to North Macedonia (US$, millions)	0.36	0.58

Source: Estimated by authors.

Annex D. National Vital Statistics Versus Corrected Data for IHD in North Macedonia from GBD 2016

National mortality statistics for 2016 in North Macedonia were provided by local experts. The vital registration data in North Macedonia is lower than data reported by GBD 2016 for IHD mortality (64 percent lower) and stroke mortality (51 percent lower). Figure D1 presents this result disaggregated by age group. Total non-external cases of mortality are estimated to be about 21,000 in GBD 2016 and about 20,500 according to the National Public Health Institute.

Figure D.1. Comparison of background mortality for IHD and stroke by age group



Source: Experts from North Macedonia National Public Health Institute (2018); and GBD 2016.

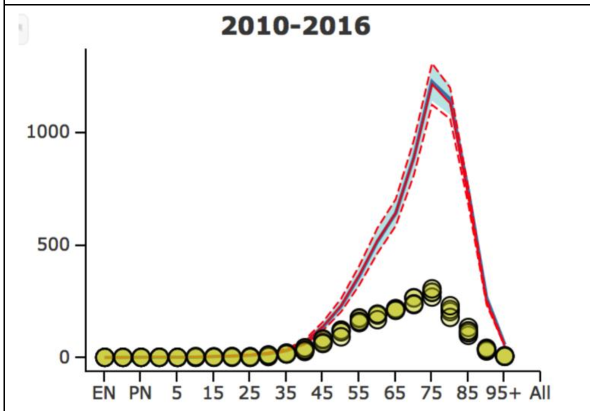
For this study, mortality statistics as reported by GBD 2016 were used. The GBD 2016 applied a correction to the national data using the CoDCorrect. CoDCorrect is a core piece of mortality machinery that is primarily responsible for making the causes of death and all-cause mortality results internally consistent.[22] Using the CoDCorrect cause hierarchy, it reads in draw files from causes of death models (CODEm and custom models). CoDCorrect will then scale all of the level 1 (based on cause hierarchy) CoD model data to the all-cause mortality envelope. In other words, after CoDCorrect, all of the level 1 causes will add up to the all-cause mortality envelope. CoDCorrect then flows down the CoDCorrect hierarchy and then scales the sub-causes of the level 1 causes to match the parent cause. The result is that all sub-causes add up to their parent cause and all CoD data add up to the all-cause mortality envelope.

Figure D2 presents cardiovascular mortality by age, for females and males separately, from the North Macedonia national database (as yellow circles) and the corrected statistics (red line). The results show a significant discrepancy between both sources with respect to cardiovascular mortality for population above 45 years of age. Figure D3 illustrates the CoDCorrect structure.

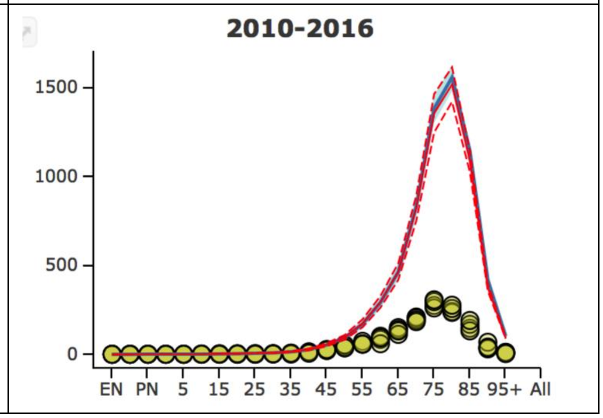
[22] Description of CoDCorrect taken from https://github.com/ihmeuw/ihme-modeling/tree/master/shared_code/central_comp/cod/codcorrect.

Figure D.2. Cardiovascular mortality in North Macedonia by age, for females and males

Males

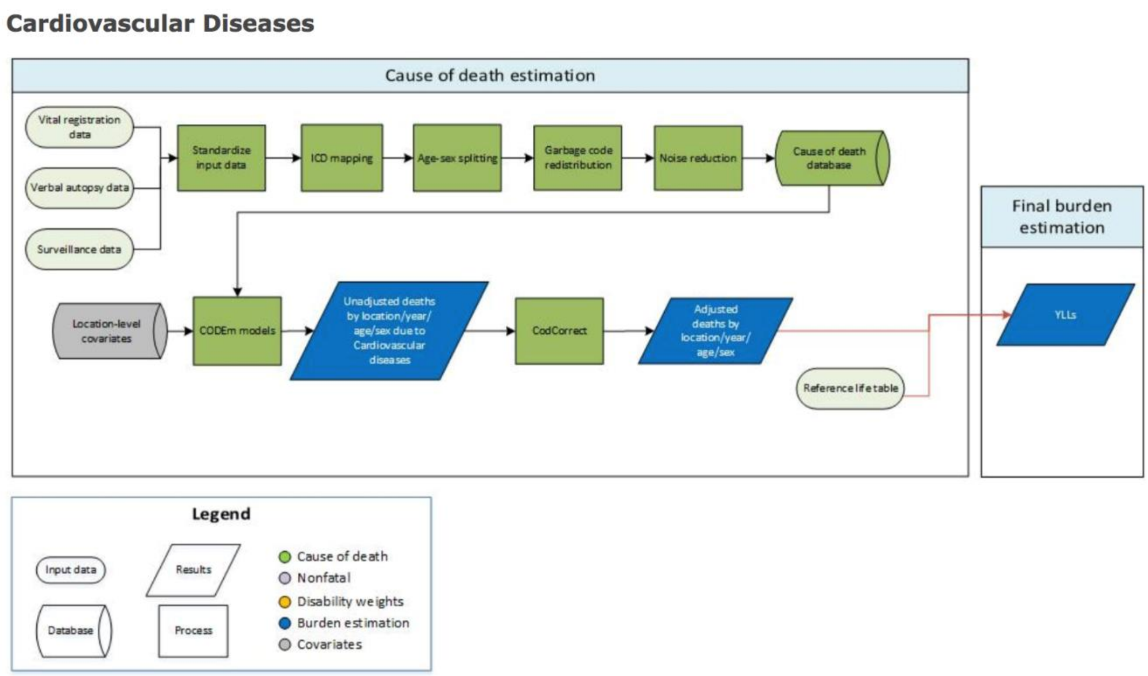


Females



Note: This code has been updated for GBD 2016: https://github.com/ihmeuw/ihme-modeling/tree/master/shared_code/central_comp/cod/codcorrect.

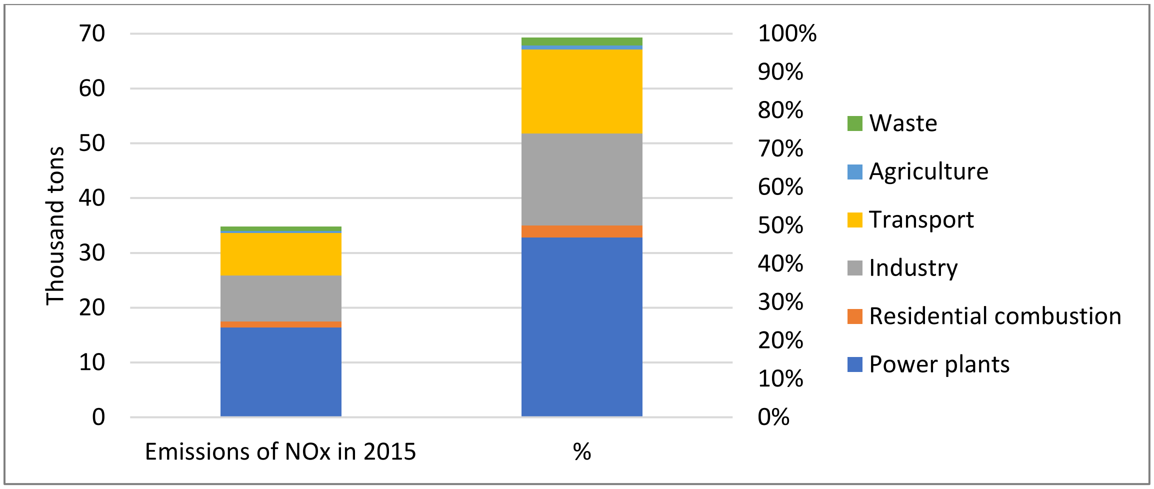
Figure D.3. Cardiovascular diseases - cause of death estimation



Source: GBD 2016. http://ghdx.healthdata.org/global-burden-disease-study-2016-gbd-2016-causes-death-2.

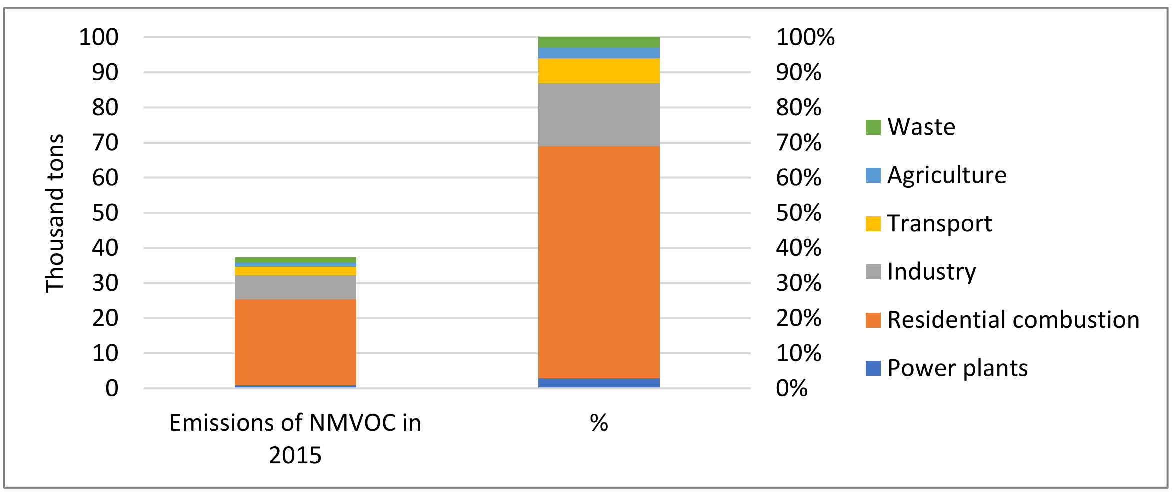
Annex E. Additional Results from GAINS Model for North Macedonia

Figure E.1. Emissions of NOx in 2015



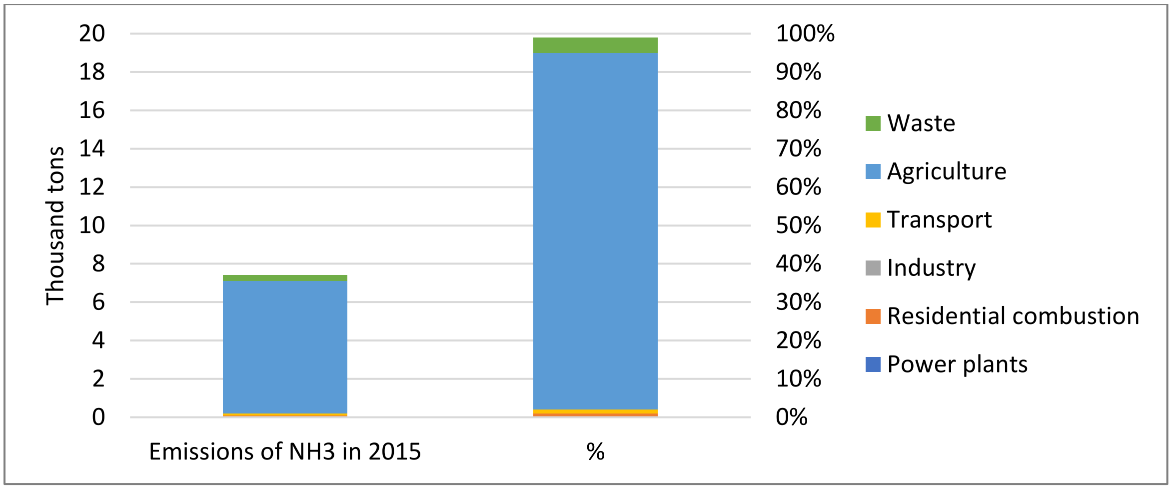
Source: GAINS Model 2018.

Figure E.2. Emissions of NMVOC in 2015



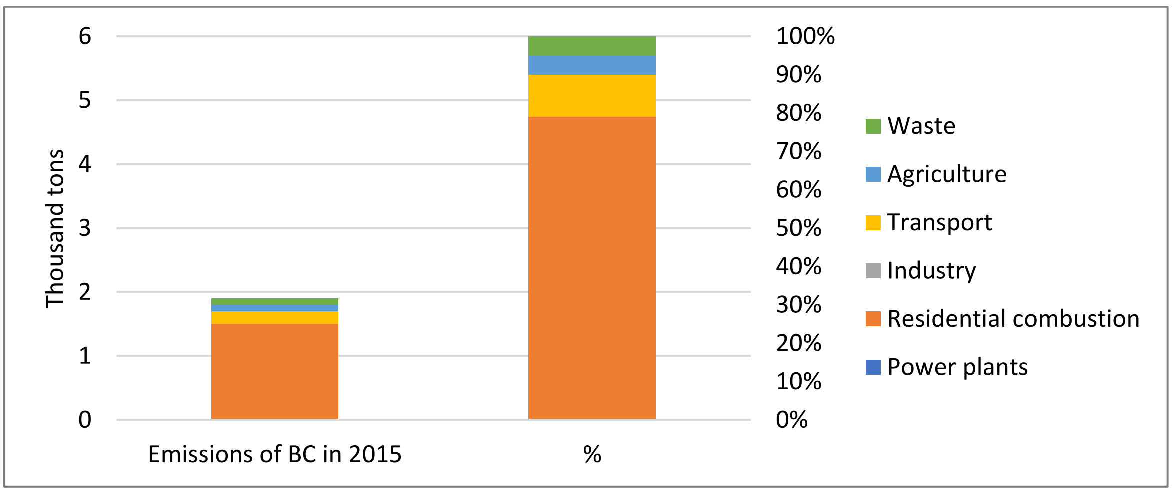
Source: GAINS Model 2018.

Figure E.3. Emissions of NH_3 in 2015



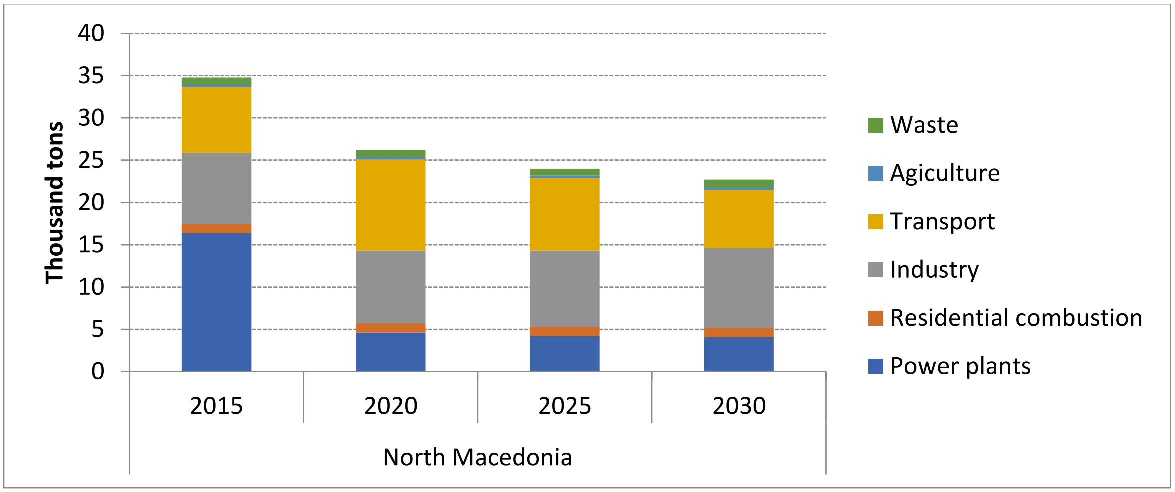
Source: GAINS Model 2018.

Figure E.4. Emissions of BC in 2015



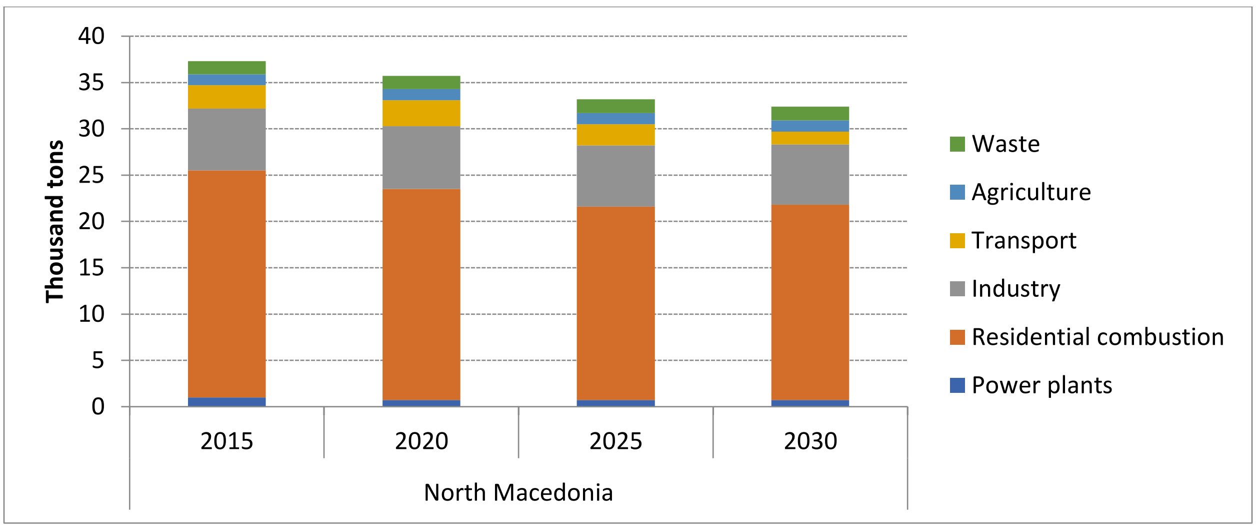
Source: GAINS Model 2018.

Figure E.5. Emissions of NO_x in the baseline scenario



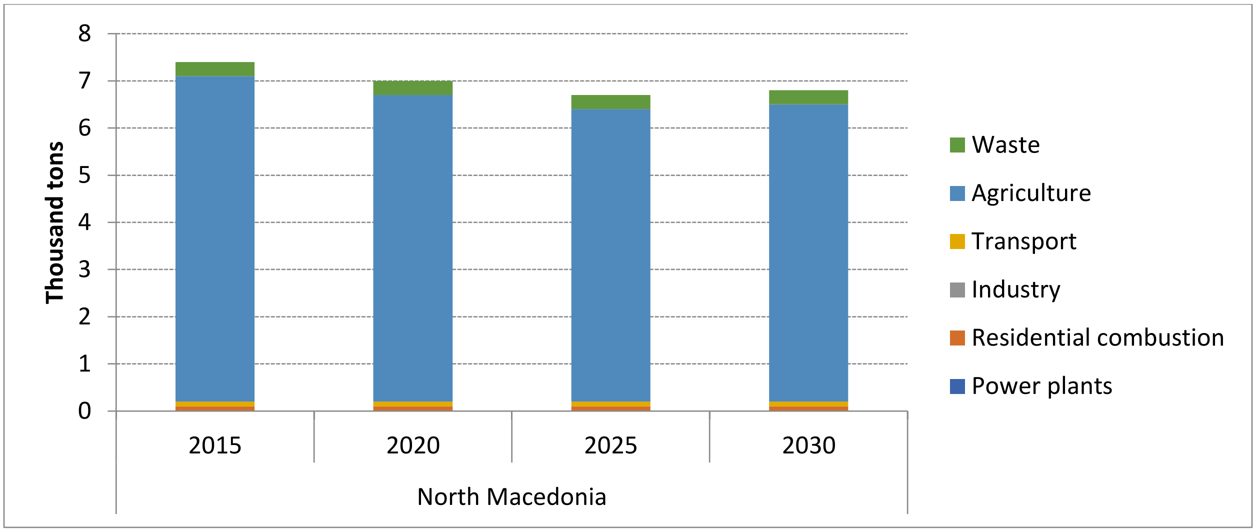
Source: GAINS Model 2018.

Figure E.6. Emissions of NMVOC in the baseline scenario



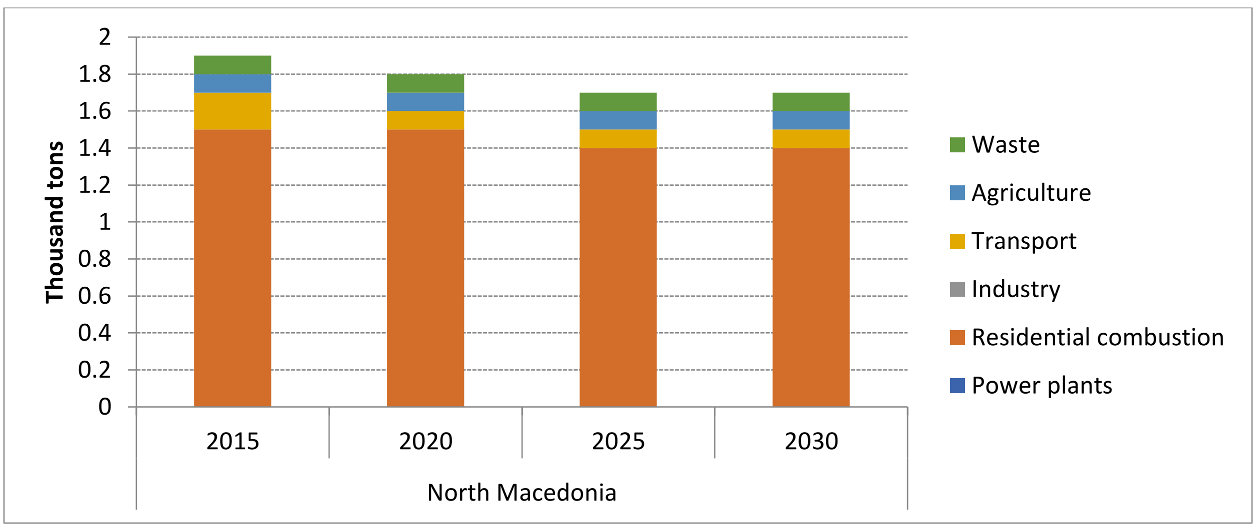
Source: GAINS Model 2018.

Figure E.7. Emissions of NH_3 in the baseline scenario



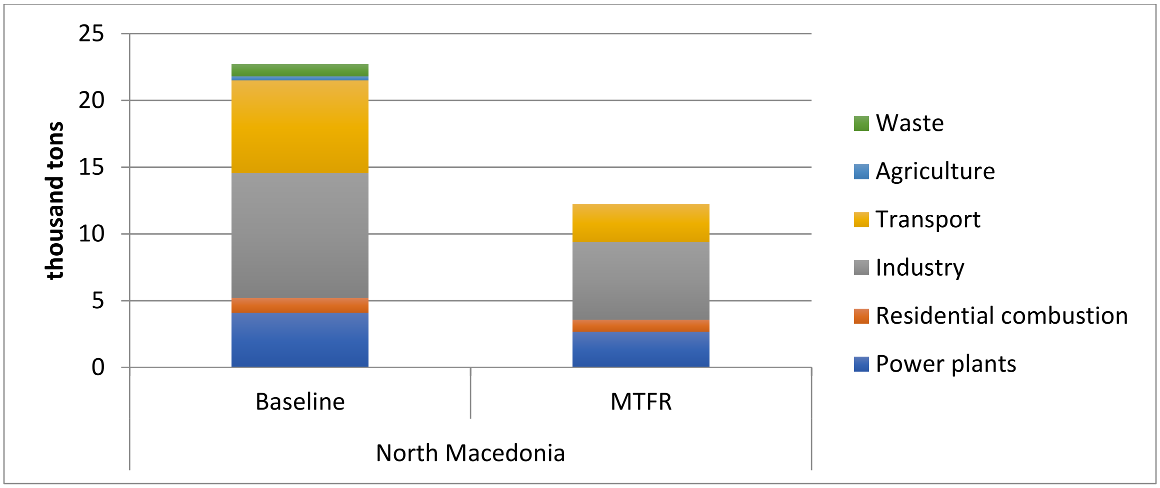
Source: GAINS Model 2018.

Figure E.8. Emissions of BC in the baseline scenario



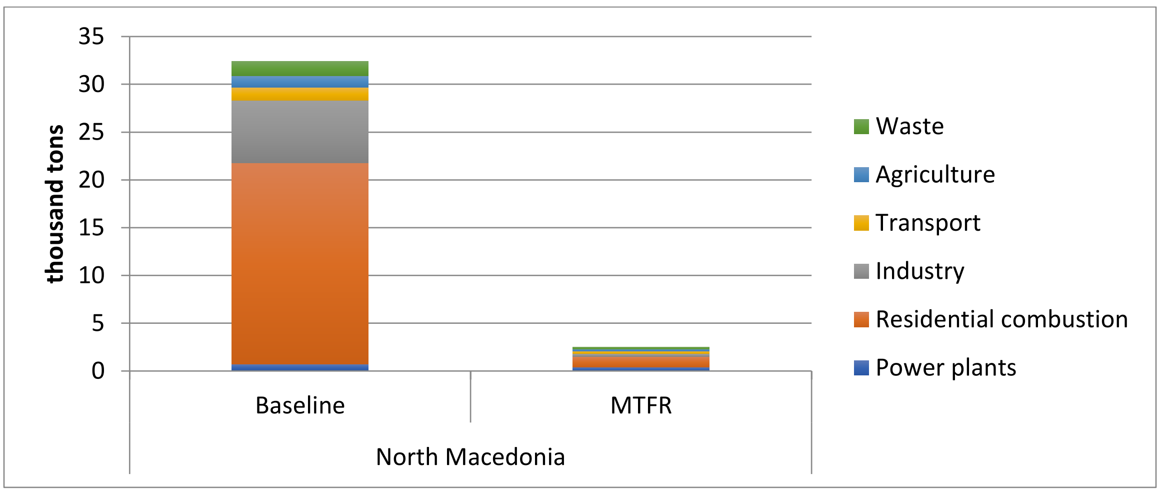
Source: GAINS Model 2018.

Figure E.9. Emissions of NO_x in 2030 for the baseline and the MTFR scenarios



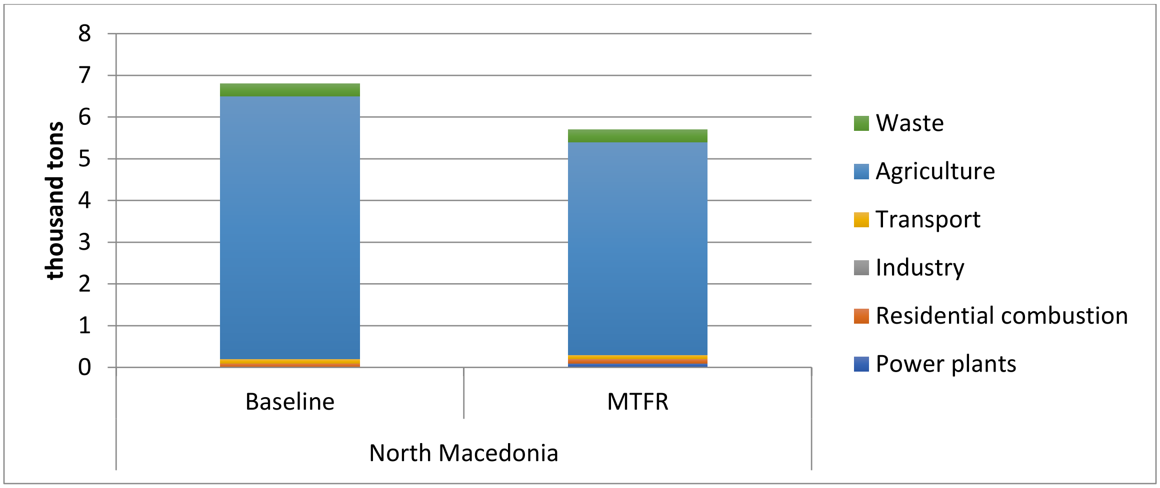
Source: GAINS Model 2018.

Figure E.10. Emissions of NMVOC in 2030 for the baseline and the MTFR scenarios



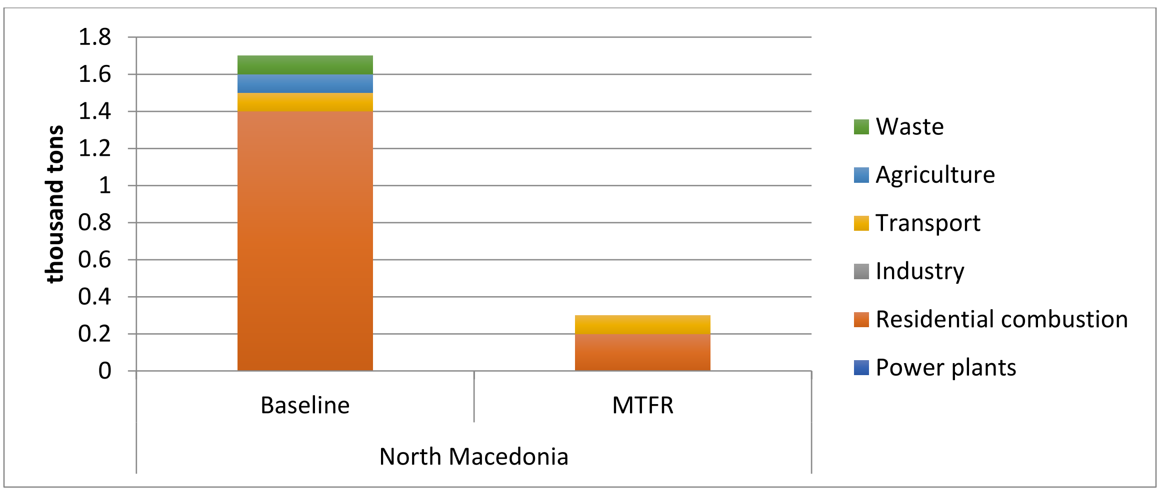
Source: GAINS Model 2018.

Figure E.11. Emissions of NH_3 in 2030 for the baseline and the MTFR scenarios



Source: GAINS Model 2018.

Figure E.12. Emissions of BC in 2030 for the baseline and the MTFR scenarios



Source: GAINS Model 2018.