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Table of Contents

Acronyms

AAP	Ambient Air Pollution
ACEA	European Automobile Manufacture's Association
AQG	Air Quality Guideline
AQ	Air Quality
AQI	Air quality index
AQP	Air Quality Plan
AQM	Air Quality Management
ASR	Anti-Smog Resolution
BAT	Best Available Technology
BAU	Business as usual

BC	black carbon
BCA	Benefit-cost analysis
BCR	Benefit Cost Ratio
B(a)P	Benzo(a)pyrene
Bn	Billion
CAFÉ	Clean Air for Europe
CAP	Clean Air Programme
CAPE	Clean Air Programme for Europe
CB	Chronic bronchitis
C_6H_6	Benzene
CIEP	Chief Inspectorate of Environmental Protection (GIOŚ in Polish)
CLE	Current legislation
CH_4	Methane
CO_2	Carbon dioxide
COI	Cost-of-illness
COPD	Chronic obstructive pulmonary disease
CP	Cardiopulmonary disease
CV	Cardiovascular disease
CLRTAP	Convention on Long Range Transboundary Air Pollution
DPF	Diesel Particulate Filter
EAP	Environmental Action Programme
EAQI	European Air Quality Index
EEA	European Environment Agency
EG	Electricity generation
ELV	Emission limit values
EPL	Environmental Protection Law
ERRs	Emission reduction requirements
EU	European Union
EU LV	European Union Limit Values
EV	Electric vehicles
GAINS	Greenhouse Gas-air Pollution Interactions and Synergies model
GBD	The Global Burden of Disease
GDP	Gross Domestic Product
GLEP	Gmina Low Emission Program
GIOŚ	CIEP - Chief Inspectorate of Environmental Protection
GoP	Government of Poland
IAQMP	Integrated Air Quality Management Planning
IED	Industrial Emission Directive
IHD	Ischemic heart disease
IHME	Institute for Health Metrics and Evaluation
HP	Heat production
IARC	International Agency for Research on Cancer (within the WHO)
IIASA	International Institute for Applied Systems Analysis
JoL	Journal of Laws
KOBIZE	National Centre for Emissions Management
kW	Kilowatt
LC	Lung cancer
LCP	Large Combustion Plants
LEAP	Low Emission Abatement Program
LHV	Light Commercial Vehicle
LRI	Lower respiratory illness
LTNDS	Long-term National Development Strategy
MCP	Medium Combustion Plants

MoE	Ministry of Environment
MHCV	Medium and Heavy Commercial Vehicle
MTFR	Maximum emission reduction potential
MS	Member State
MTFR	Maximum Technical Mitigation Potential
Mtoe	Megatoe; Unit of energy equal to 106 toe – tonnes of oil equivalent
MW	Megawatt
NAQP	National Air Quality Plan
NEC	National Emission Ceilings
NECD	National Emission Ceilings Directive
NFEP&WM	National Fund for Environmental Protection and Water Management
NH_3	Ammonia
NMVOCs	Non-methane volatile organic compounds
NO_x	Nitrogen Oxides
NRAQP	National and regional air quality plans
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
PAF	Population attributable fraction
PAH	poly aromatic hydrocarbon
PAQI	Polish Air Quality Index
PLN	Polish złoty (currency)
Pb	Lead
PEC	Primary energy consumption
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a diameter of less than 2.5 µm
PM_{10}	Particulate matter with a diameter of less than 10 µm
PPP	Purchasing power parity
PRIMES	Price-Induced Market Equilibrium System
SAO	Supreme Audit Office
SEM	State Environmental Monitoring
SFB	Single-family building
SO_2	Sulfur Dioxide
STAP	Short-Term Action Plan
RR	Relative risk
TSP	Total Suspended Particulates
TWh	Terawatt-hour
UNECE	United Nations Economic Commission for Europe
VOC	Volatile Organic carbon
VFEP	Voivodeship Fund for Environmental Protection
VIEP	Voivodeship Inspectorate of Environmental Protection
VSL	Value of statistical life
WB	World Bank
WDI	World Development Indicators
WHO	World Health Organization
WTP	Willingness-to-pay
µg/m^3	microgram per cubic meter

List of Figures

List of Tables

List of Boxes

Executive Summary

Ambient Air Quality in Poland

Despite significant efforts to reduce polluting air emissions, during and after the economic transition in the 1990s, Poland remains home to many of the most polluted cities in the European Union (EU). This report examines the nature and magnitude of ambient air pollution (AAP) in Poland. It provides estimates of the health burden, and economic cost associated with the health impacts, of ambient air pollution i.e., particulate matter ($PM_{2.5}$) both at national and regional or voivodeship levels in Poland. It also explores the roles of various sources of air pollution emissions on ambient air quality in Poland. With emphasis on the critical residential sector, this report analyses the likely impacts of national and EU legislative scenarios on future pollution emissions and ambient air quality in Poland. In addition, the report performs a demonstrative cost-benefit analysis of selected interventions to reduce AAP in residential and transport sectors and from point sources in the voivodeships that bear the heaviest burden of the impacts of AAP. Institutional factors that affect the effectiveness of ambient air quality management are discussed. Finally, policy recommendations for air pollution prevention, reduction and abatement are presented.

Many people in Poland are exposed to levels of ambient air pollution, notably particulate matter ($PM_{2.5}$), that are harmful to health. $PM_{2.5}$ is the cause of disease and death associated with lung cancer, chronic obstructive pulmonary disease, ischemic heart disease, stroke, respiratory illness. Annual average ambient concentrations of fine particulate matter, $PM_{2.5}$, concentrations are often multiple times the maximum levels allowed under EU law (25 $\mu g/m^3$) and the WHO air quality guideline value (10 $\mu g/m^3$). The most widespread exceedances of EU air quality Limit Values are seen in south and southwestern Poland.

At the base of Poland's air quality challenges is the country's heavy dependence on coal as a source of fuel. Significant amounts of coal are used in residential and commercial heating, and in industry and power production. The residential and industrial sectors account for the largest shares of energy consumption at 29% and 29.9% respectively, followed by the transport (24%) and commercial (17.2%) sectors (IEA, 2017). There has been a significant reduction in the total quantity of coal used since socialist times, and notable increases in the use of natural gas and renewable energy sources. However, coal, which is generally a more highly polluting energy source, is still dominant. It is projected that by 2020, Poland will account for about 50% of hard coal use by small consumers in Europe.[1]

[1] Price-Induced Market Equilibrium System (PRIMES) Reference 2016 scenario. PRIMES is an EU energy system model.

The significant health and economic impacts of ambient air pollution call for a paradigm shift. In particular, dedicated efforts are needed to shift from a heavy reliance on coal to a more sustainable growth path that reduces environmental and health impacts of coal reliance, including through shift to use of cleaner fuels in households, industry and power generation, and curbing transport emissions.

The residential sector is the most important source of ambient $PM_{2.5}$ pollution in most areas in Poland although existing national inventories likely underestimate emissions from the sector. Burning of polluting solid fuels such as coal, coal wastes, biomass and wastes for heating purposes in small boilers and individual stoves in households is the main source of ambient $PM_{2.5}$ pollution. The residential sector is also the leading source of Benzo[a]pyrene, a known carcinogen. The contribution of the residential sector to ambient air pollution is most evident during winter months i.e., peak heating season. Notwithstanding the important role of the sector, existing national emissions inventories suffer systemic uncertainties related to real-life emissions; activity statistics, specifically information gaps about use of coal wastes (i.e., coal muds and flotation residue) and non-commercial biomass use in stoves and boilers; and burning of waste materials in residential heating installations. Additional important contributors to ambient particulate matter pollution are industry, energy and road transport. The energy sector continues to be an important source of SO_2 and NO_x, and transport a source of NO_x, although SO_2 and NO_x are not widespread problems across the country.

While most attention to date has focused on the residential sector, the contributions to AAP, of additional sources such as transport and transboundary sources, need to be better understood and quantified. During warmer months of the year contributions from other sources such as transport could become more prominent. Poland’s car fleet is the oldest and sixth largest in the EU and continues to grow. Older cars without adequate emission controls could be important contributors of air pollution, particularly in cities or areas with high density of transport networks. However, uncertainties relating to emissions contributions, particularly related to actual mileage and environmental performance of used imported vehicles, need to be addressed. In addition, in parts of southern Poland, transboundary sources contribute a significant share of AAP, reaching more than 60% in śląskie voivodeship (SAO, 2018). In order to better assess and target domestic AAP mitigation measures, increased collaborative approaches at the regional level may be called for to complement domestic measures and enhance air quality outcomes.

Health Burden and Economic Cost of Ambient Air Pollution in Poland

Exposure to ambient $PM_{2.5}$ imposes an enormous health burden and productivity losses on the Polish population. This report estimates that AAP is associated with 23% of the annual burden of bronchitis in children and 33% of the annual burden of chronic bronchitis in adults.

The highest burden is in mazowieckie and śląskie voivodeships. AAP resulted in 213,313 cases of bronchitis in children, 49,061 cases of chronic bronchitis in adults, 19,139 hospital admissions for respiratory illness and 16,847 lost days of work. It is also associated with 2% of the cardiovascular and 4.5% of respiratory hospital admissions and 8% of the total lost workdays. The morbidity burden is highest in wielkopolskie, mazowieckie, śląskie, łódzkie, and małopolskie voivodeships. The overall morbidity burden is accentuated during winter months when pollution levels are elevated due to increased residential heating, and spikes occur in cardiovascular and respiratory hospital admissions and respiratory infections. The daily burden of morbidity attributable to short-term air pollution is at least 1.6-2 times higher in winter months than in other seasons.

This report conservatively estimates that 25,280 premature deaths are caused by ambient $PM_{2.5}$ pollution in Poland in 2016. Following the Global Burden of Disease (GBD) 2016 methodology, this conservative approach calculates premature, age specific mortality from five diseases - lung cancer, ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), and lower respiratory illness – that are directly linked to $PM_{2.5}$ pollution. By contrast, the recent EEA 2018 estimate of 44,500 deaths, is for all-cause or non-accidental mortality (i.e., all deaths excluding poisoning, suicide and war), and assumes a linear relationship between mortality and $PM_{2.5}$ concentration for population above age 30.[2]

On average, premature deaths attributed to ambient air pollution (AAP) account for approximately 6.4% of total mortality in Poland in 2016 and mortality rates are highest in voivodeships in southern Poland. The rate of mortality attributed to ambient air pollution is estimated at 66 per 100,000 on average in Poland. However, this number increases to 71-82 per 100,000 in voivodeships in the south and southwest of Poland, notably dolnośląskie, łódzkie, małopolskie, śląskie, and świętokrzyskie. The number of deaths attributed to ambient air pollution is highest in śląskie, mazowieckie, małopolskie, and wielkopolskie voivodeships. Prioritizing interventions to reduce AAP in these voivodeships will have the most significant impact in reducing the substantial health burden.

The economic cost associated with disease and premature death from exposure to ambient $PM_{2.5}$ is estimated at US$31- 40 billion, equivalent to 6.4-8.3% of GDP in 2016, using the welfare-based approach and US$3 billion, equivalent to 0.6% of GDP in 2016, using foregone output-based approach. The total cost of morbidity is estimated at about US$1.05 billion and working adults carry the largest share or 75% of this cost, related to lost work days due to illness. Based on forgone output, morbidity accounts for about 40% of the total cost of health

[2] For comparative purposes, this report also estimates that 44,811 deaths are caused by AAP, applying the methodology used in EEA (2018). The estimates from both sources are very close.

damages. The total cost of health damage from ambient air pollution is highest in mazowieckie and śląskie voivodeships. The welfare-based cost exceeds total current expenditures on health care (both public and private) in 2015 (US$30 billion) in Poland. The total annual budget of the National Health Fund, the publicly funded healthcare system in Poland, is about US$18 billion in 2016. On a per capita basis, the voivodeships in the south and southwest of Poland bear the most significant annual cost, with śląskie and dolnośląskie bearing cost in the range of US$1100-1200/person if a national value of statistical life (VSL) is used for mortality valuation. The costs could increase up to US$1200-1300/person, in śląskie voivodeship, when calculated based on the individual VSL of each voivodeship.

Future Emission and Air Pollution Scenarios

Full implementation of the requirements of adopted and planned national and regional/voivode legislation (NRAQP scenario) will bring substantial air quality and health benefits. The development of $PM_{2.5}$ emissions into the future is affected by the legislative environment, in the case of Poland being EU regulations and national air quality legislation. With a primary focus on the residential sector, this report used the GAINS model to simulate impacts of different scenarios of EU, and existing and recently adopted national legislation in Poland, on emissions of $PM_{2.5}$ (and $PM_{2.5}$ precursors). The results showed that ambitious and early actions targeting solid fuel heating installations in the residential sector, through implementing requirements of existing and planned national and regional legislations, including the National Air Quality Plan, Clean Air Programme, standards for fuel boilers, national fuel quality standards and regional Anti-smog requirements (e.g. expedited implementation of Class 5 or Eco-design boilers and scrapping of existing boilers that are non-compliant with Eco-design), supported by financial mechanisms, will bring substantial reductions of primary $PM_{2.5}$ emissions especially in the south of Poland, thus significantly enlarging the areas of the country that comply with EU Limit Value and WHO air quality guideline value for $PM_{2.5}$.

However, in order to achieve compliance with Poland's emission reduction requirements under the National Emissions Ceiling Directive (NECD) and bring ambient air quality closer to the WHO $PM_{2.5}$ guideline value (10μg/m^3), further measures will be needed to address ammonia emissions from agriculture, an important source of secondary particulate matter pollution, and emissions from industry. Without additional actions to curb ammonia emissions, agriculture, the key source of ammonia emissions, will become an even more important contributor to the formation of ambient $PM_{2.5}$. The application of nitrogen-containing fertilizers in agriculture leads to the emission of ammonia, which combines with NO_x and SO_x from other sources such as power plants and traffic, to form secondary particulate matter pollution. The need for further reductions of $PM_{2.5}$ emissions from industry would depend on successful implementation of Polish national and regional air quality legislation scenario, and effective implementation could minimize the need for additional measures in industry. PM emissions control costs increase over time underscoring the need for timely action. Recent legislation on advanced Euro 6 standards is expected to deliver a significant decrease in emissions from mobile sources.

Although switching to new, high efficiency stoves and boilers will reduce coal consumption and thus CO_2 emissions from Polish households, this reduction will be limited. Expansion of cleaner energy sources such as gas and district heating could possibly provide higher CO_2 reductions. Given the significant amounts of coal used in the Polish residential sector, this report examined the potential for CO_2 mitigation from this sector using the GAINS model. It is estimated that the introduction of new stoves and boilers with higher efficiency will result in about 10% reduction of CO_2 emissions from coal combustion in this sector, which translates to about 5% reduction of total emissions from the residential sector or less than 1% reduction in the total national CO_2 emissions in 2030. Consequently, only limited CO_2 mitigation potential is estimated from coal combustion in Polish households when only switching to more efficient stoves and boilers is pursued. Higher reductions could possibly be achieved with further expansion of gas and district heating, but this would require analysis to be confirmed.

Interventions to Reduce Air Pollution from Different Sectors in the Voivodeships where Cost of AAP is Highest

Benefit-cost analysis provides an informed basis for prioritizing interventions to reduce air pollution from different sectors particularly in voivodeships where the mortality and morbidity costs of ambient air pollution are highest. Based on scenarios developed in this study with the GAINS model, results of voivode-level source apportionments conducted by the Polish Supreme Audit Office (SAO, 2018), a World Bank study on financial instruments for supporting energy efficiency in single family buildings (SFBs) in Poland (World Bank, 2018) and other sources, this report conducted benefit-cost analysis (BCA) of interventions to reduce air pollution from the residential sector, transport and point sources in four voivodeships: i.e., mazowieckie, małopolskie, śląskie and dolnośląskie where the costs per capita of ambient air pollution are highest in the country. The BCA allows a comparison of the health benefits of an intervention i.e., avoided cost of premature mortality and morbidity, and cost of implementation of the intervention. It should be noted that the range of interventions studied in this report are not exhaustive but instead demonstrate the usefulness of BCA for selecting and targeting interventions to reduce AAP beyond a single sector.

Interventions to replace old, polluting residential boilers are economically effective alone and when combined with full or partial retrofit of single family buildings in all four voivodeships. BCA showed that all interventions examined - replacement of old boilers with new ones; replacement of boilers and partial thermal retrofit of SFBs; and replacement of boilers and full thermal retrofit of SFBs - are economically viable i.e., yield benefit-cost ratios (BCRs) greater than one. In all voivodeships, replacement of old boilers was more economically effective than the other two interventions. BCRs were highest in mazowieckie and małopolskie voivodeships indicating that interventions in these voivodeships should be prioritized. The analysis assumed a gradual shift to gas boilers and an increase of municipal heating connections.

BCA of transport sector interventions suggest that implementation of the government's electromobility plan is economically effective in urban centers in three of four voivodeships, and interventions should be prioritized in śląskie voivodeship. The three interventions analyzed included structural changes in the automobile fleet, specifically (i) replacement of a share (10%) of the oldest cars with new ones that meet at least Euro 5 standards; (ii) implementation of Poland's electromobility plan by 2025 with 1 million electric and hybrid vehicles registered; and (iii) implementation of (i) and (ii). Implementing the electromobility plan was found to be economically viable in all voivodeships except dolnośląskie, and most viable in śląskie voivodeship. The quantified benefits of electromobility did not include additional benefits such as strengthening of electricity transmission and distribution grids, job creation and boosts to GDP growth, which would call for further analysis within a general equilibrium framework.

The results of BCA to reduce pollution from point sources (high stacks) suggested prioritization of interventions in śląskie voivodeship. For point sources, a group of interventions to reduce pollution from high-stack point sources (power generation and industry) including in-furnace control-limestone injection, enforcement of low-sulfur coal (0.6% sulfur content) use, and wet flue gas desulfurization were analyzed. BCRs of unity or greater were achieved only in śląskie voivodeship. However, uncertainties related to how the transboundary nature and uniform character of emissions from high-stacks may affect the results need to be better understood.

Policy and Institutional Aspects of Air Quality Management in Poland

There is a need to consolidate and clarify roles and responsibilities for air quality management at the national level. Poland has two high level officials with air quality-related responsibilities at the national level: the Minister of Environment, and the Plenipotentiary of the Prime Minister, who is appointed by the Prime Minister and has the responsibility to coordinate government activities to implement the recommendations of Poland's Clean Air Programme. In addition, the Plenipotentiary is responsible for cooperation with local government units of different levels and non-governmental organizations, and international cooperation. None of these functions are part of any existing administrative unit of the government, such as the Ministry of Environment. Consolidating and clarifying roles and responsibilities for air quality management at the national level would help to avoid potential inefficiencies associated with duplication and overlaps of roles.

Poland has a complex and decentralized institutional framework for air quality management. However, a coordinated, central institutional approach is needed to bring consistency to addressing air quality management in Poland. Roles and responsibilities of entities involved in air quality management in Poland are divided between several representatives of national, regional and local governments. Decentralization does have its merits, notably that responsible government agencies can more readily respond to local environmental management problems. However, with the decentralized structure come challenges in ensuring uniformity of air quality management efforts and standards across levels of government, as well as variations in budgetary and technical resources and capacity. The effects of these challenges are most notably felt at the local level where exposure to ambient air pollution affects the day-to-day lives of citizens.

In Poland, variability in fundamental elements of air quality planning at the local level is symptomatic of the challenges of the decentralized governance structure for air quality management. Air Quality Plans (AQPs) are developed at the local level by the voivodeships and suffer some shortcomings, which pose constraints to their effectiveness: they vary across voivodeships in their treatment of different elements of air quality planning; and needed technical guidance to strengthen the effectiveness of their design is lacking, out of date or not mandatory. The robustness of AQPs mirrors variations in the level of funding and technical capacity across regions. Some AQPs tend to have more of a diagnostic rather than prescriptive focus, and do not have adequate information to implement an integrated air quality management approach. Strengthening the Ministry of Environment to play a central role, which has an overall coordinating role and sufficient technical expertise, and provides uniform guidance to voivodeships for AQP development, could greatly improve this process. The differences in approaches to air quality planning across voivodeships provides an opportunity for stock-taking of regional experiences. Experiences from around the world indicate that the existence of an apex organization (e.g. the Ministry of Environment), is crucial in promoting coordination across regions and across different levels of government, facilitating stock-taking, identifying lessons learned and fostering knowledge exchange across regions as part of efforts to ensure consistency of approaches.

At the local level, a strengthened approach to Integrated Air Quality Management (IAQM) is needed, which is based on establishment of comprehensive and accurate emissions inventories, prioritizing residential and transport sectors. The establishment of complete and accurate emission inventories, which adequately capture all sources of polluting air emissions, is the bedrock of IAQM, an approach that is based on source emissions and ambient air quality monitoring data; atmospheric dispersion and deposition, pollutant concentrations, health risk assessment and the costs and benefits of abating emissions. Data for residential emission inventories in Poland are often of poor quality and suffer from large uncertainties, and for these reasons likely to underestimate emissions from the residential sector. Given the prominent role of the residential sector in contributing $PM_{2.5}$ emissions, accurately capturing and inventorying the emissions of this sector are critical for effective air quality management in Poland. Similarly, information on transport sector emissions is not fully understood, especially in relation to the contributions of imported used cars, which do not have adequate emission control technology – and account for about a third of new registrations - needs to be more carefully captured. The government's ongoing efforts through the National Center for Emissions Management to strengthen emission inventory development should be continued and supported.

Poland has established an extensive national air quality monitoring network but could expand monitoring of health damaging air pollutants, including fine particles ($PM_{2.5}$), ultrafine particles, and chemical species and constituents of PM. Poland has established a comprehensive national air quality monitoring network. Monitoring of the more harmful to health $PM_{2.5}$ is a more recent development than measurement of PM_{10}. The need for $PM_{2.5}$ monitoring is underscored by recent findings of Burnett et al., 2018, which indicate that $PM_{2.5}$ may be implicated in more health outcomes than currently included in global estimates, and as such the global health burden attributable to $PM_{2.5}$ may be significantly larger than previous global estimates. Continued monitoring of $PM_{2.5}$ should be expanded and monitoring systems can be strengthened by incorporating the measurement of ultrafine particulate matter, notably black carbon, an air pollutant that also has climate warming properties. Given Poland's heavy dependence on coal, monitoring of chemical constituents and species of PM that are associated with combustion of solid fuels is also recommended. Chemical constituents and species associated with combustion sources have long- and short-term health effects and monitoring them could help to better understand such health impacts on the Polish population (World Bank, forthcoming).

Development of mandatory technical guidance for IAQM - including use of air dispersion models, and source apportionment, health impact and cost-benefit analyses in Air Quality Plans (AQPs) - is needed. Technical guidelines for conducting dispersion modeling, source apportionment and health risk assessment in AQPs is often voluntary and does not provide sufficient guidance to support the development of effective AQPs. There are various ways to improve the AQPs. They should concentrate more on quantitative rather than qualitative data. Emission inventories of the residential sector need to be greatly improved. Emission inventories are inconsistent in quality and methods used across the voivodeships. There should be consistent methods for estimating emissions from the residential sector, including standardized emission factors, applied in the same manner in all voivodeships. Background concentrations of pollutants should be incorporated in modelling in a uniform way. AQPs should include source apportionment analysis at a minimum for PM. However, there are not uniform guidelines for which models and methods to use for dispersion modeling or for source apportionment modeling. Air quality issues in some voivodeships are partially due to transboundary pollution from other parts of Poland and sometimes other countries, requiring cooperation with neighboring Voivodeships. Such needed consistent and comprehensive guidance could be developed by the Ministry of environment. Furthermore, to avoid the problem of variability or inconsistency in the quality of AQPs across voivodeships, the Ministry could play a role in reviewing and approving AQPs prepared by the voivodeships. In addition, mechanisms could be put in place to ensure that application of guidance is mandatory, for example through updates to the Regulation on air quality plans and short-term action plans.

Poland should transition toward adoption of a more health-based approach to dissemination of air quality information (air quality index). Although air quality is publicly disseminated online in real-time in Poland, the Polish Air Quality Index is not based on health criteria, and therefore underestimates the real health risks of air pollution to the public. This can be misleading in terms of representing air quality status and for informing precautionary or protective measures to be taken by sensitive groups and other members of the public. The Polish alert threshold for PM_{10} is the highest among the EU Member States. As $PM_{2.5}$ is now the foundation of air pollution health risk assessment, alerts should eventually be based on $PM_{2.5}$ concentrations.

Under its Clean Air Program (CAP), Poland has made important accomplishments notably, the recent adoption of regulations on solid fuel quality. However, strong government measures will need to be taken to enforce bans on low-quality coal fines by 2020 and to make fuel quality standards more stringent in the short to medium term especially with respect to coal quality standards for households and other small consumers. The new fuel quality regulations for small consumers include quality specifications for low-quality coal fines (grain size of 1mm-31.5mm). Coal fines can be sold until June 2020. However, enforcing the ban on its use in households may be difficult and the government will need to take strict measures, including incentives to enforce the ban. Furthermore, the new fuel quality regulations specify up to 1.7% sulfur content for coal for small consumers. By comparison, in some other coal-consuming countries, sulfur content of hard coal, for all consumers, is: Czech Republic (0.42-0.43%); Turkey (0.8-1.0%); and Germany (0.45-1.8%).[3] The Polish government should take steps to further reduce the sulfur content of solid fuel.

The government will need to eliminate gaps in regulations that could allow boiler manufacturers to by-pass recently adopted legal technical requirements for small-scale solid fuel boilers. In October 2017, the government introduced for the first time a regulation on technical requirements for small-scale solid fuel boilers for use in residential and service sectors. The regulation prohibits the sale of the more polluting no-class, class 3 and class 4

[3] https://euracoal.eu/libraray/annual-reports/

boilers effective July 2018, and introduced emission requirements for class 5 boilers in line with the European Commission's Ecodesign Regulation. However, boiler manufacturers could find ways to by-pass the regulation for example by renaming old-type biomass boilers and selling them as "non-woody biomass" boilers and by describing no-class coal boilers originally designed for building heating as hot water heaters. Under the new regulation, installations including boilers for heating drinking water, and "non-woody biomass" boilers are excluded from the new technical requirements. The government will need to develop and enforce legislation to eliminate such gaps that could allow manufacturers to by-pass the law.

The recent enactment of the law on electromobility and alternative fuels is illustrative of the government's commitment to promote low-emission transportation. Careful consideration should be given to distributional impacts of implementing low-emission initiatives. The national Electromobility Development Plan, launched in March of 2017 envisages 1 million electric cars in Poland by 2025 and provides for a system of incentives. The law introduces the creation of low-emission zones by municipal governments in densely built-up areas. Implementation of the law provides potential opportunities for economic development, in addition to environmental improvements. Given the relatively old age of Poland's vehicle fleet and that people of lower economic status are more likely to drive older vehicles, the government could consider understanding the distributional impacts of implementing low-emission initiatives.

The government should put in place mechanisms to support the broader adoption of anti-smog resolutions (ASRs) that ban the residential use of low-quality solid fuels in voivodeships. A number of voivodeships and agglomerations have voluntarily adopted ASRs, aimed to reduce the adverse impacts of air pollution from the residential sector through restrictions on individual heating installations and solid fuels that are allowed for burning. In małopolskie voivodeship, for example, the ASR for Kraków agglomeration bans the burning of solid fuels in domestic installations, effective September 1, 2019. So far ASRs have been adopted in about 50% of voivodeships, and their wider adoption throughout the country should be encouraged and supported through appropriate financial mechanisms and strengthened public education and awareness on the provisions of ASRs.

Better tracking of funding and public expenditures enhances air quality management particularly in voivodeships where the cost of AAP is highest. Sufficient funding for air quality management is necessary to ensure that actions to reduce air pollution can be adequately carried out. In Poland, funding for environmental management comes from various sources: national, regional, international and others. The government collects fees based on emission registries, and administrative fines as penalties for exceeding permit emission limits. Payments are made by businesses and institutions which emit various pollutants, from both stationary and mobile sources. However, the residential sector is the leading contributor to PM emissions.

Although in principle fees are based on the polluter pays principle, determining the effectiveness of fees in reducing pollution from fee payers merits further study. Revenues from environmental penalties are low in comparison to the monetary value of penalties imposed pointing to the need to strengthen collection of penalties: between 2015 and 2017, revenues from environmental penalties amounted to only 12-18% of the monetary value of penalties imposed.

Understanding criteria for prioritizing activities to be funded and ensuring that environmental expenditures are aligned with air quality management priorities are important for enhancing implementation effectiveness of AQPs. In some countries, public environmental expenditure reviews have been used in informing priority setting for air quality management and could be a valuable tool at the regional level, particularly in the voivodeships where the cost of health damage from ambient air pollution is highest.

Recommendations

Key recommendations of this report are summarized in Table ES.1.

Table ES.1. Recommended Actions

Strengthening Air Quality Monitoring and Emissions Inventories
Transition to a system of monitoring and analysis that is based primarily on $PM_{2.5}$ pollution.
Expand monitoring efforts to include chemical constituents and species (e.g. elemental carbon, organic carbon, sulfates, nitrates, ammonium, heavy metals), as well as air pollutants such as black carbon which causes adverse health impacts and is also a climate warmer.
Develop comprehensive and accurate emission inventories for (i) solid fuel combustion in the residential sector and (ii) fuel use in the transport and non-road mobile sources sectors
Strengthening Institutional Capacity for Air Quality Management
Consolidate and clarify roles and responsibilities for air quality management at national and sub-national levels
Strengthen the central management capacity of the Ministry of Environment so that it can coordinate the activities at the voivodeship level with uniform and consistent guidance for air quality planning and management.
Strengthen technical capacity in voivodeships to prepare and implement air quality plans through development of uniform technical guidance for AQP development, including (i) emission inventory preparation, notably for residential and transport sectors; (ii) air dispersion modeling; (iii) source

apportionment; (iv) health impact analysis; (v) cost-benefit analysis; (vi) inclusion of performance indicators in AQPs.
Implement the Integrated Air Quality Management framework in air quality planning
Incorporate cost-benefit analysis in decision-making for targeting pollution reduction interventions in the areas of highest health risk
Clarify and strengthen responsibilities and accountability structure within AQPs
Ministry of Environment should review and approve all Voivodeship air quality plans for quality and consistency.
Maintain accurate emission registries for the environmental fee system through periodic technically accurate inspections.
Strengthening Legal and Regulatory Framework for Air Quality Management
Adopt the long-term goal of achieving the WHO Guideline of 10 $\mu g/m^3$ which is a health-based standard
Require application of strengthened uniform technical guidance in development of air quality plans
Enforce requirements to have new buildings connected to municipal heating networks and to expand distribution networks for natural gas to replace coal use
Policy Reforms and Investments for Improving Air Quality
Adopt a more health-based Poland Air Quality Index for dissemination of air quality information
Implement the new regulation on the minimum quality requirements for solid fuels for the residential sector and track its implementation
Adopt more stringent quality standards for solid fuels such as for sulfur and ash content
Develop programs to control agricultural and industrial emissions
Develop programs to get the oldest and dirtiest diesel fueled cars off the road
Focus on reducing and controlling ambient $PM_{2.5}$ pollution with actions in the voivodeships where the health and economic costs of ambient air pollution per capita are the highest.
Ensure continued financial support for replacement of old boilers in the residential sector under the Clean Air Priority Programme
Put in place mechanisms to support broader adoption of ASRs, including financing and public awareness and education promotion

Put in place mechanisms for technical experts with technical and professional AQM experience to be involved in review process for preparation of AQPs and AQP updates, and in
Put in place mechanisms to ensure that gmina-level programs (e.g. LEAPs and GLEPs) are consistent with AQPs, and accountabilities for air quality outcomes are clearly outlined
Filling Knowledge Gaps for Air Quality Management
To further reduce particulate matter concentrations, support analytical work to better understand the contribution of agricultural emissions to air quality
Conduct analysis to understand distributional impacts of implementing low-emission transport measures
Conduct analysis to understand the effectiveness of fees and fines in reducing air pollution emissions.
Target pollution reduction interventions to reduce pollution loads associated with the highest health risks
Conduct expenditure review for air quality planning and management at national, regional and local levels
Conduct stock-taking and dissemination of regional experiences and lessons learned in AQM to facilitate knowledge exchange and sharing among regions.

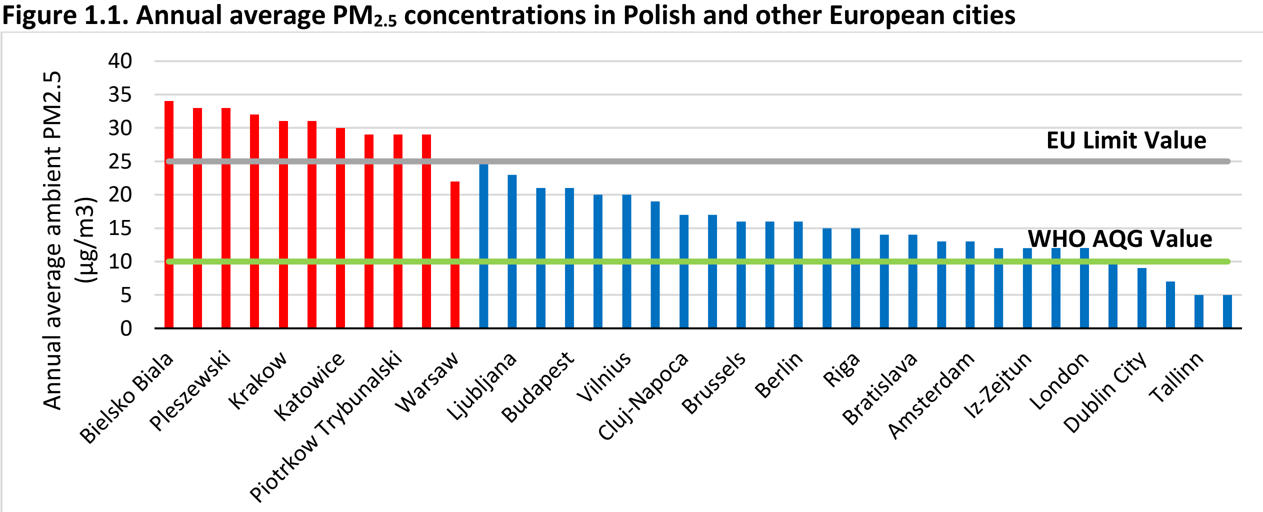
Chapter 1. Ambient Air Quality in Poland

Introduction

Poland has many of the most polluted cities in the European Union (WHO 2018). In these cities, large populations are exposed for extended periods to ambient concentrations of fine particulate matter ($PM_{2.5}$) well above both the health-based WHO Air Quality Guideline value of 10 µg/m^3 and the less-stringent European Union Limit Value of 25 µg/m^3 (Table 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, stroke, chronic obstructive pulmonary disease and respiratory disease.

According to the latest World Health Organization's global ambient air quality database,[4] Poland has among the worst air quality in Europe—23 of the 50 European cities with the highest ambient levels of $PM_{2.5}$ are in Poland, as are 18 of the 50 European cities with the highest ambient levels of PM_{10} (Figure 1.1). In 2016, the mean population exposure to $PM_{2.5}$ in Poland was 25.6 µg/m^3, which is more than double the WHO guideline value.

Figure 1.1. Annual average $PM_{2.5}$ concentrations in Polish and other European cities



Source: WHO Global Ambient Air Quality Database (2018)

Ambient concentrations of particulate matter are significantly higher during winter months and during evening hours and weekends, because the burning of highly-polluting solid fuels for residential heating is the source of 80% of total $PM_{2.5}$ emissions in the country. These fuels include poor quality coal, coal wastes and fuelwood, which are typically burned in small

4 WHO Global Ambient Air Quality Database (Update 2018) can be found at: http://www.who.int/airpollution/data/cities/en/

combustion devices (i.e. boilers and individual stoves in households) that have poor or non-existent emission controls).

Table 1.1. EU Ambient Air Quality Limit Values and WHO Guidelines

Pollutant	Averaging Period	EU LVs ($\mu g/m^3$)	WHO Guideline ($\mu g/m^3$)	Number of Allowed Exceedances By EU
PM_{10}	Annual	40	20	
	Daily	50	50	35 per year
$PM_{2.5}$	Annual	25	10	
			25	
Nitrogen Dioxide (NO_2)	Annual	40	40	
	1-hour	200	200	18 per year
Ozone (O_3)	8-hour	120	100	25 per year, averaged over 3 years
Sulfur Dioxide $\mu g/m^3$	1-hour	350	20	24 per year
	Daily	125	500	3 per year

Source: EU (2008)

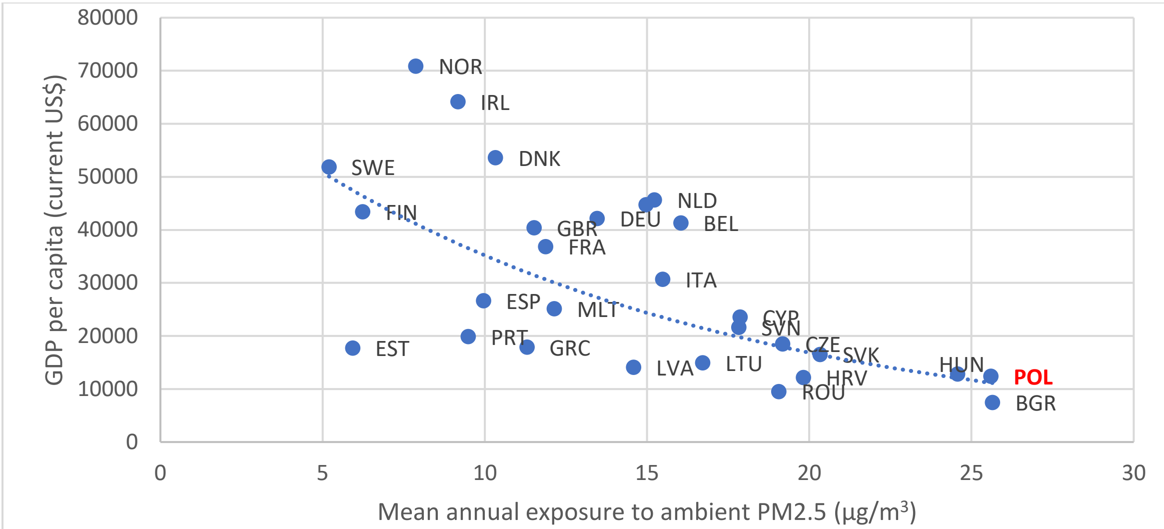
In 2015, the European Commission took Poland to court over its failure to address its persistent non-compliance with the EU Air Quality Standards for PM_{10}.[5] In February 2018 the European Court of Justice ruled that Poland had indeed violated the European Union law on air quality by continuously exceeding PM_{10} limits from 2007 to 2015,[6] and that it needed to improve air quality and reduce PM_{10} levels. PM_{10} daily limit values had been exceeded in 35 zones and annual limits had been exceeded in 9 zones. For reference, the WHO Guideline values and the EU Limit Values for various air pollutants, which are also Poland's Limit Values, are both shown in Table 1.1.

Widespread frustration with Poland's air pollution has in recent years led civil society groups to create the Polish Smog Alert and Local Smog Alerts. As of May 2018, 27 Local Smog Alerts exist—mainly in southern and central parts of Poland. The Smog Alerts are the work of activists working in different towns and cities in concert with local officials, physicians, the academic community, the Catholic Church and others.

Figure 1.2. Income and Urban Pollution Levels across European Countries

5 http://europa.eu/rapid/press-release_IP-15-6225_en.htm

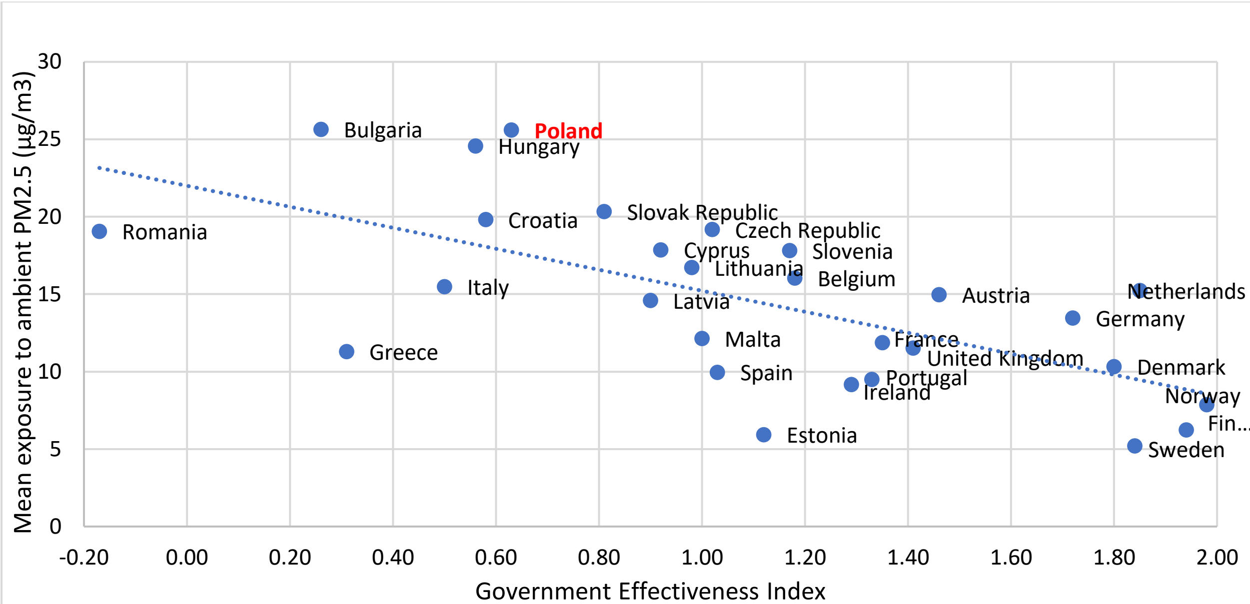
6http://curia.europa.eu/juris/document/document.jsf?text=&docid=199566&pageIndex=0&doclang=EN&mode=lst&dir=&occ=first&part=1&cid=324672



Source: Data from World Bank, World Development Indicators (2018)

Usually, countries with a higher GDP per capita have less ambient air pollution. However, Poland has higher pollution levels than similar-income countries in Europe (Figure 1.2). Similarly, environmental quality indicators correlate with governance indicators such government effectiveness, voice and accountability, political stability, regulatory quality, rule of law, and control of corruption (Figure 1.3). 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, the quality of the civil service, and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. Some of these governance issues are relevant to air quality management and could be relevant to the institutional framework for air quality management in Poland. As can be seen from the figure, a positive correlation exists between government effectiveness and air quality. Poland has higher levels of ambient air pollution than some other European countries with lower government effectiveness indexes. The institutional framework for air quality management in Poland is complex and decentralized. Given that exposure to ambient air pollution is primarily local, a coordinated and consistent approach by government authorities at all levels of government, including the availability and deployment of effective guidance and tools at the local level, are needed.

Figure 1.3. Government effectiveness and air pollution ($PM_{2.5}$)



Source: World Bank 2018

Historical Evolution of Ambient Air Quality

During the socialist era (between the Second World War and 1989), the extensive heavy industry and the inefficient use of raw materials and of energy, mainly coal, all led to Poland becoming one of the most polluted countries in Europe with very high ambient concentrations of gaseous pollutants such as SO_2, particulate matter - measured at that time as Total Suspended Particulates (TSP), and heavy metals.

Ambient air quality monitoring in Poland began in the 1950s although such efforts were at the time discontinuous and selective. Sample maximum short-term TSP concentrations from the 1970s were as high as 1470 µg/m^3 in Łódź and 860 µg/m^3 in Warsaw. Using established conversion methods, these TSP concentrations would be approximately 445 µg/m^3 in Łódź and 260 µg/m^3 in Warsaw of $PM_{2.5}$, which are extremely high notwithstanding conversion uncertainties (Larson et al., 1999, Strukova et al., 2006, Avaliani & Revich 2010). By the 1980s, air quality was regularly monitored in southern Poland, in Upper Silesia Industrial District and Krakow.

Beginning in 1989 Poland transitioned to a market economy. With this change came increased recognition of the need to integrate environmental and economic reforms in Poland and other transition economies, to solve the serious environmental problems associated with inefficient use of natural resources and pollution of air, water and land by industry during the socialist era. In 1993, an Environmental Action Programme (EAP) for Central and Eastern Europe was adopted by environment ministers from Central and Eastern European countries, the New

Independent States of the former Soviet Union and OECD countries (OECD, 1999a). The EAP promoted the adoption of economic reforms combined with institutional strengthening and cost-effective investments to tackle the region's most important environmental issues in the short to medium term (Zamparutti et al., 2000).

Box 1.1. Poland's major air pollutants

Particulate Matter (PM) - $PM_{2.5}$, is the most harmful subset of PM_{10}, and a known carcinogen. Primary particles come from combustion of fossil fuels, especially coal and diesel, in domestic heating and cooking, vehicles and industry, and burning of waste crop residues. Secondary particles are emitted from power plants, industries, agricultural activities and vehicles, and are formed in atmospheric reactions between other pollutants.

Nitrogen Oxides (NO_x) – A gas which at higher concentrations can irritate the airways of the lungs. Emitted by automobiles, industrial activities, and combustion in power plant boilers. In 2016 there were 4 zones that exceeded EU Limit Values (LVs), namely the cities of Warsaw, Krakow, Katowice and Wroclaw.

Ozone (O_3) - A gas which can adversely affect the respiratory system even at relatively low levels and is not emitted directly from any source. According to Poland's Environment 2016 report (CSO, 2016), 26 of the 64 monitoring sites in Poland exceeded the EU LVs during 2015.

Toxic air pollutants – This group includes benzo[a]pyrene or B[a]P; benzene; polychlorinated biphenyls; volatile organic compounds, dioxins, and furans, which are products of incomplete combustion of carbon-based fuels. Air toxics are implicated in higher rates of cancer, immune or neurological damage, genetic defects, and heart and respiratory issues. In 2015, 44 of Poland's 46 assessment zones exceeded the EU's B[a]P Target value of 1 ng/m3 (EEA 2017).

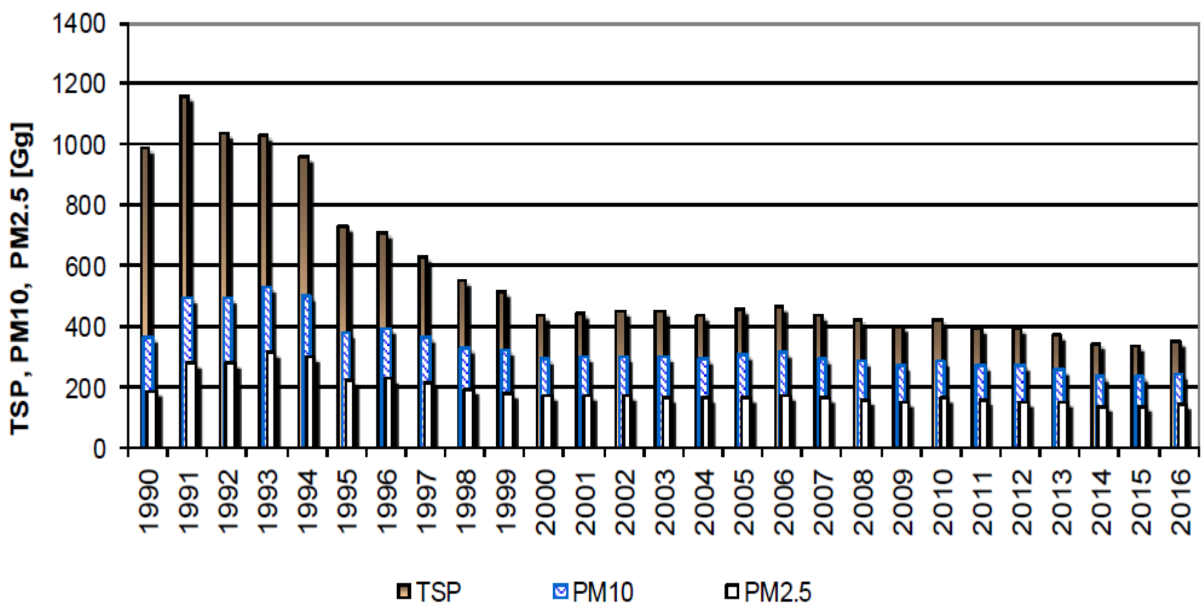
Heavy metals – Airborne heavy metals can cause disease and death. In addition to lead and arsenic this group includes cadmium, manganese, mercury, and nickel. In 2015, Poland had two of three monitoring sites within the Europe network which were non-compliant with the EU Threshold Value of 6 ng/m^3 for arsenic (EEA, 2017). Arsenic is a local issue in Poland and is typically associated with local industrial operations.

Sulfur Dioxide (SO_2) – 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. SO_2 can affect the respiratory system and irritate the eyes. Although historically an issue, SO_2 is no longer a significant issue in Poland.

Poland was one of the advanced reformers under the EAP. Economic reforms helped generate resources for investment in cleaner, more efficient technologies, reduced the share of pollution-intensive heavy industries in economic activity, and helped control pollution and waste generation as part of the shift towards more efficient production methods. The passage of important policies such as fuel switching away from coal, improved efficiency and environmental policies leading to adoption of modern pollution control technologies all helped to achieve significant emission reductions (OECD, 2003). Notably, an OECD study found that, between the late eighties and mid-nineties in advanced reform countries, economic restructuring and environmental actions appeared to have played an important role in reducing air pollution as average trends in emissions of particulate matter, SO_2 and NO_x decreased faster than gross domestic product (GDP) as economies shrank and continued to decrease, even after GDP levels began to grow (OECD, 1999b). These results attested to Poland's progress in decoupling emission of air pollutants from economic and industrial growth.

In the late eighties and early nineties there were large reductions (50-75%) in annual average particulate matter in Poland's cities, although ambient concentrations remained an important public health concern. Ambient SO_2 concentrations also fell from 1987/88 levels by greater than 50% in eight out of nine provinces studied. In the industrial "hot spot" of Upper Silesia, ambient concentrations fell markedly between the early nineties and late nineties despite increasing industrial production. A switch to cleaner fuels, investments in new capital stock, and air pollution abatement measures all contributed to improving air quality in Upper Silesia. Coupled with these changes, Poland undertook environmental policy reforms. Notably, the country significantly increased its pollution charges early in the transition and used the revenues to finance pollution abatement investments.

Figure 1.4. Trend in TSP, PM_{10} and $PM_{2.5}$ Emissions in Poland between 1990 and 2016.



Source: KOBIZE, 2018.

Figure 1.4 shows the sharp decline in emissions of particulates during the early 1990s and the more ambiguous movement in concentrations during the last fifteen years. SO_2 and NO_x followed a similar trend. Between 1990 and 2016, emissions of SO_2 and NO_x decreased by about 80%, and over 30% respectively. Additional information on ambient concentrations can be found in Annex A.

Recent Air Quality – Improvements and Remaining Challenges

In Poland, air quality is assessed in two ways: the ambient concentration of a pollutant relative to the EU Limit Value and the number of exceedances of the Limit Value of a pollutant relative to the EU allowed number of exceedances per year. As shown in Table 1.1, EU Limit Values for particulate matter are less stringent than WHO air quality guideline values. Furthermore, there is no EU daily average Limit Value for $PM_{2.5}$. This section reviews the status of ambient air quality and identifies areas where challenges remain in achieving compliance with ambient air quality standards.

Improvements in Air Quality

At a national level, Poland's emission reduction efforts over the past three decades have led to noticeable reductions of ambient concentrations of key pollutants. Today, NO_2 and SO_2 pollution are not widespread problems across Poland. In 2016 four air quality zones exceeded EU Limit Values, namely in the cities of Warsaw, Krakow, Katowice and Wroclaw[7]. Out of 138 monitoring sites in 2016, only six exceeded the annual mean EU Limit Value of 40µg/m^3, and no site had more than the allowed 18 exceedances of the hourly EU Limit Value. SO_2 is not a significant issue compared to other legislated pollutants. This is due to large reductions in SO_2 emissions across Europe as a result of a combination of measures, including fuel-switching in energy-related sectors away from high-sulfur solid and liquid fuels to low-sulfur fuels such as natural gas, the fitting of flue gas desulfurization abatement technology in industrial facilities and the impact of European Union directives relating to the sulfur content of certain liquid fuels. In 2016, none of the 136 sites measuring SO_2 in Poland recorded exceedances of the hourly or daily EU LVs. Ozone is also not a widespread problem in Poland. The highest concentrations are seen in the southern and southwestern parts of the country. In 2015, 26 of 64 sites monitoring ozone in Poland exceeded the EU LV (CSO, 2016).

Ambient Particulate Matter - A Remaining Environmental and Health Challenge

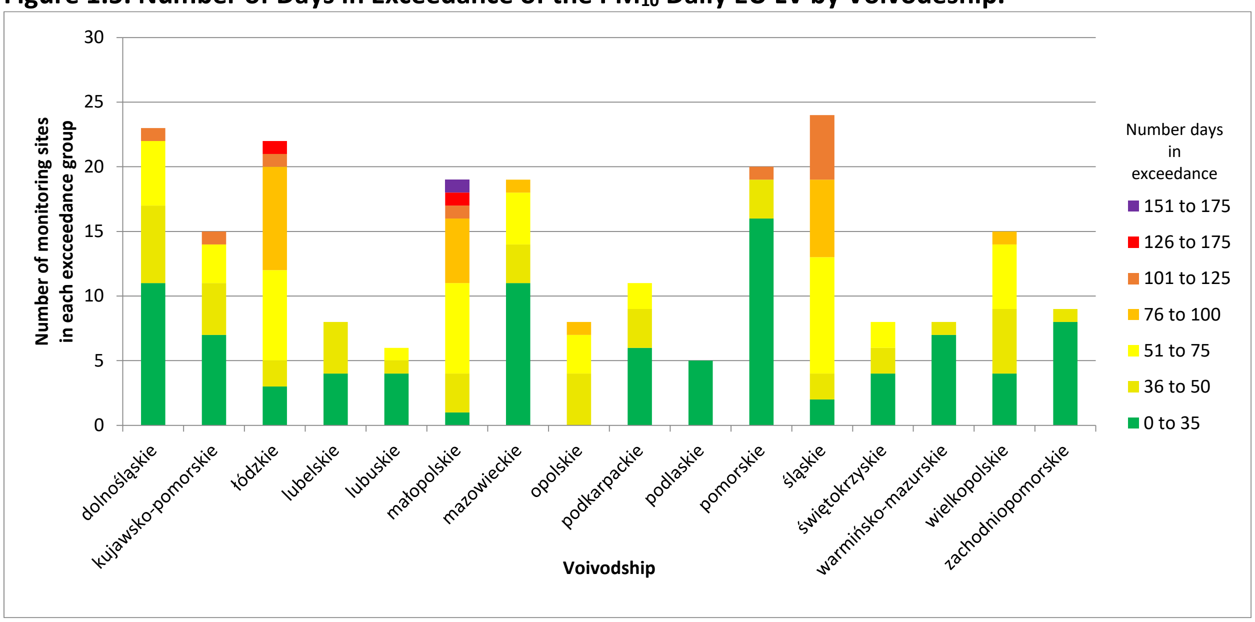
Poland continues to face challenges in ensuring compliance with EU standards for particulate matter, specifically Limit Values and numbers of exceedances. In the move away from focusing upon measurements of Total Suspended Particulates (TSP) to the more scientifically valid health-based indicators of particulate pollution, measurements of PM_{10} concentrations across

7 Maps of Annual air quality assessments - http://powietrze.gios.gov.pl/pjp/maps/air/quality/type/R

Polish cities and agglomerations began in 2005. Measurements of the more health-damaging $PM_{2.5}$ began five years later in 2010.

PM_{10} - With respect to PM_{10} annual mean concentrations across the cities and agglomerations[8] of Poland have decreased, but still often remain above the EU Limit Value of 40µg/m^3. In 2016, the agglomerations of Katowice, Rybnicko-jastrzębska and Krakow had the highest concentrations of PM_{10}. Additional information on PM10 concentrations is presented in Annex A (Figure A.1 and Figure A.2). PM_{10} monitoring data from 229 monitoring sites, showed that 127 were non-compliant with the daily mean EU Limit Value of 50µg/m^3. In 2016, only one voivodeship, podlaskie, recorded no exceedances of the daily Limit Value. Nine voivodeships had at least one monitoring station exceeding the EU LV on 100 or more days during 2016 with małopolskie and łódzkie voivodeships having locations exceeding on more than 125 days (Figure 1.5). Median concentrations ranged from 119 µg/m^3 to 380 µg/m^3. The exceedances of the daily EU LV are therefore significant in nature with local populations across almost all voivodeships exposed to very high short term PM_{10} concentrations

Figure 1.5. Number of Days in Exceedance of the PM_{10} Daily EU LV by Voivodeship.



Source: Authors based on the Chief Inspectorate for Environmental Protection air quality portal.

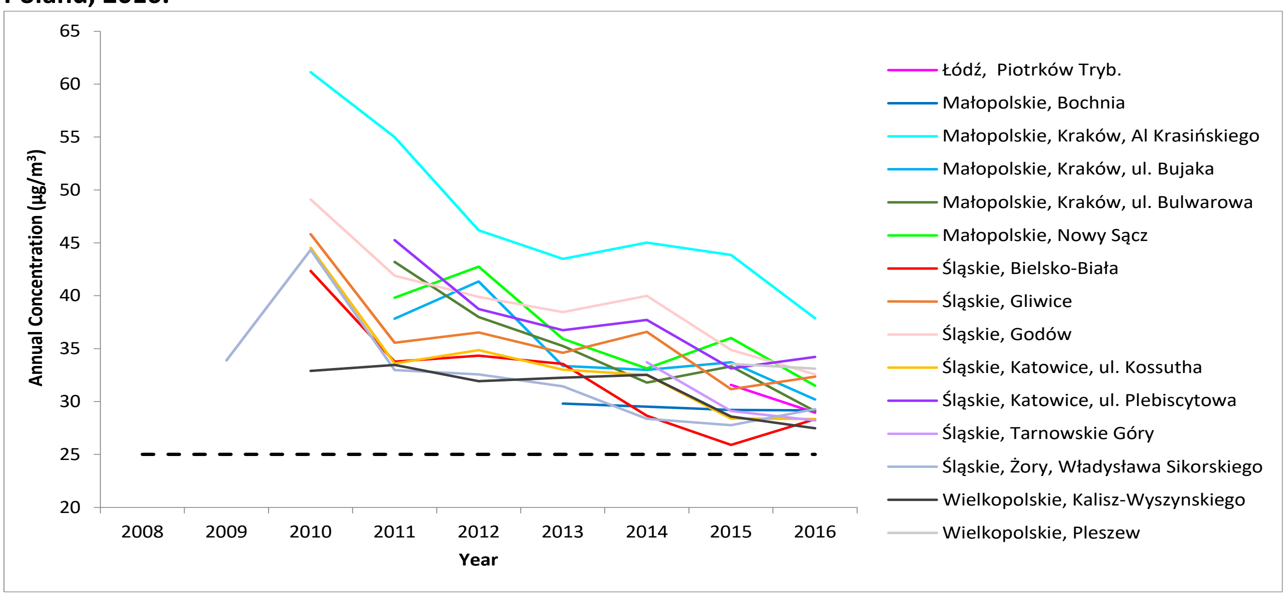
$PM_{2.5}$ – High concentrations of $PM_{2.5}$ are the most serious remaining air quality problem in Poland most importantly for health reasons. $PM_{2.5}$ has become the most important indicator of

8 Agglomeration is defined by in the reports as a city or several cities with common administrative boundaries with a population exceeding 250,000 inhabitants.

air quality and has been steadily replacing PM_{10} in monitoring and air quality management systems around the world.

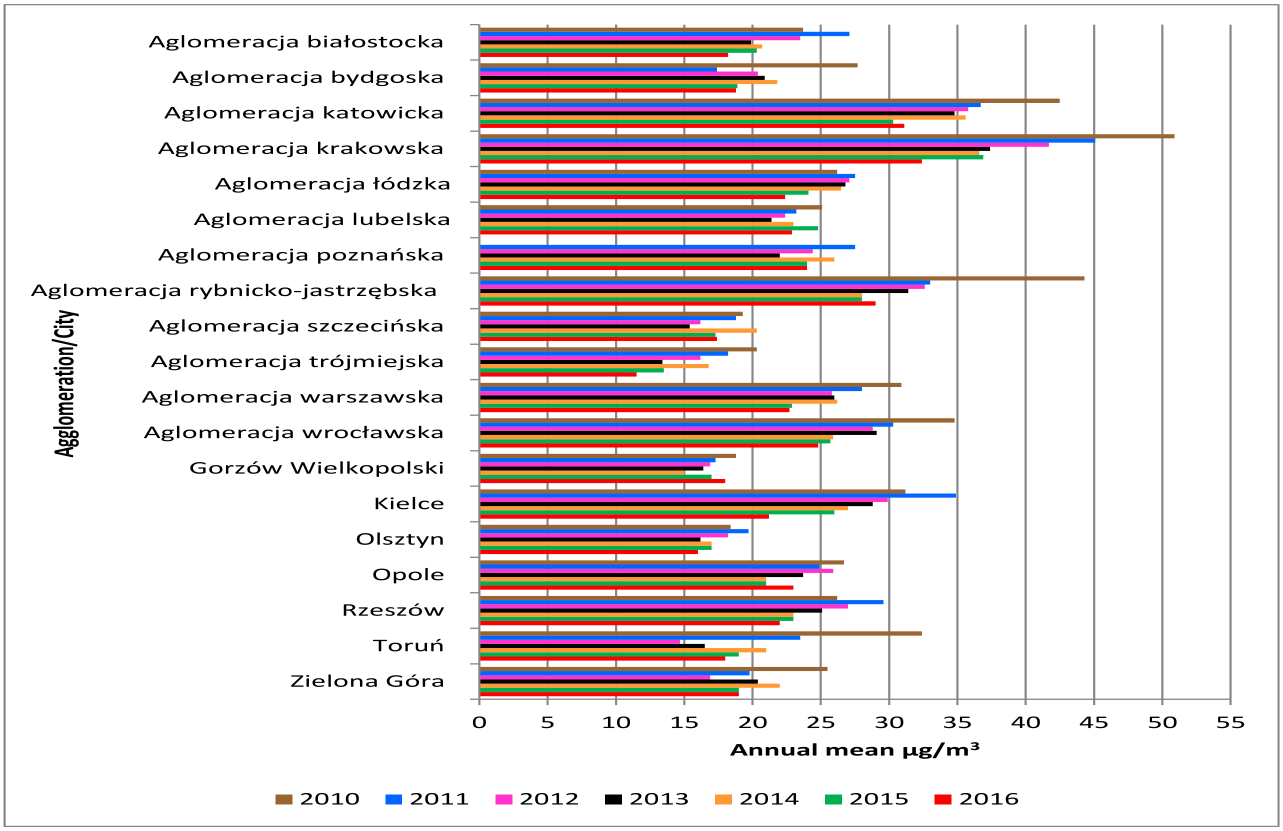
Concentrations of $PM_{2.5}$ pollutant show the same general patterns as the PM_{10} concentrations: significant progress in reducing concentrations and significant room for improvement (Figure 1.6). Between the years 2010 (when most $PM_{2.5}$ monitoring started) and 2016 there were concentration reductions at all of the fifteen most polluted sites in Poland. However, none of the sites recorded annual ambient concentrations below the EU Limit Value of 25 µg/m^3, and therefore they also have never been below the WHO guideline (2006) of 10 µg/m^3. The three agglomerations with the highest annual average concentrations exceeding the EU LV in 2016, are Katowice, Rybnik-jastrzębska and Krakow (Figure 1.7). In 2016, 32 of the 93 $PM_{2.5}$ monitoring locations recorded exceedances of the annual mean EU LV. Many of the exceedances were measured within the Voivodeships of małopolskie (including the city of Krakow) and śląskie (including the city of Katowice). There were also exceedances in the larger cities including Warsaw, Wroclaw, and Łódź.

Figure 1.6. Trends in annual mean $PM_{2.5}$ concentrations at the 15 most polluted monitoring sites in Poland, 2016.



Source: Authors based on data from the Chief Inspectorate for Environmental Protection air quality portal.

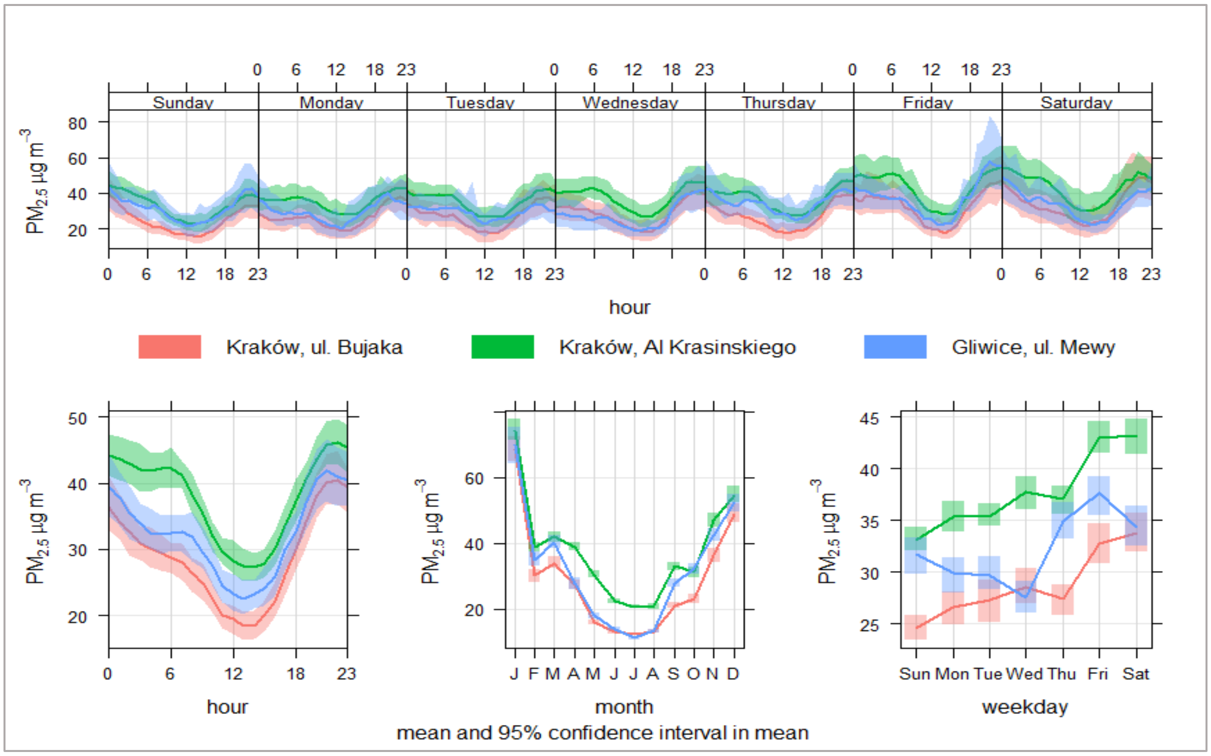
Figure 1.7. Average Annual Mean $PM_{2.5}$ Concentrations in Cities and Agglomerations Across Poland.



Source: Statistics Poland (2017)

The seasonality of $PM_{2.5}$ pollution can be seen at the three sites with both the highest annual mean concentrations and monitoring that provides hourly concentrations of $PM_{2.5}$ (Figure 1.8). Pollution levels are higher in the winter because the main source of ambient $PM_{2.5}$ is burning of polluting solid fuels in small boilers and individual stoves for residential heating. This is also why air quality is worst from 6pm and midnight and on the weekends—these are the times when people are most likely to be at home and actively heating. Diurnal trends show only very weak peaks in the morning related to peak traffic flow during the morning commute, suggesting that non-traffic sources of $PM_{2.5}$ are more significant.

Figure 1.8. Temporal analysis of $PM_{2.5}$ hourly concentration from 2016.

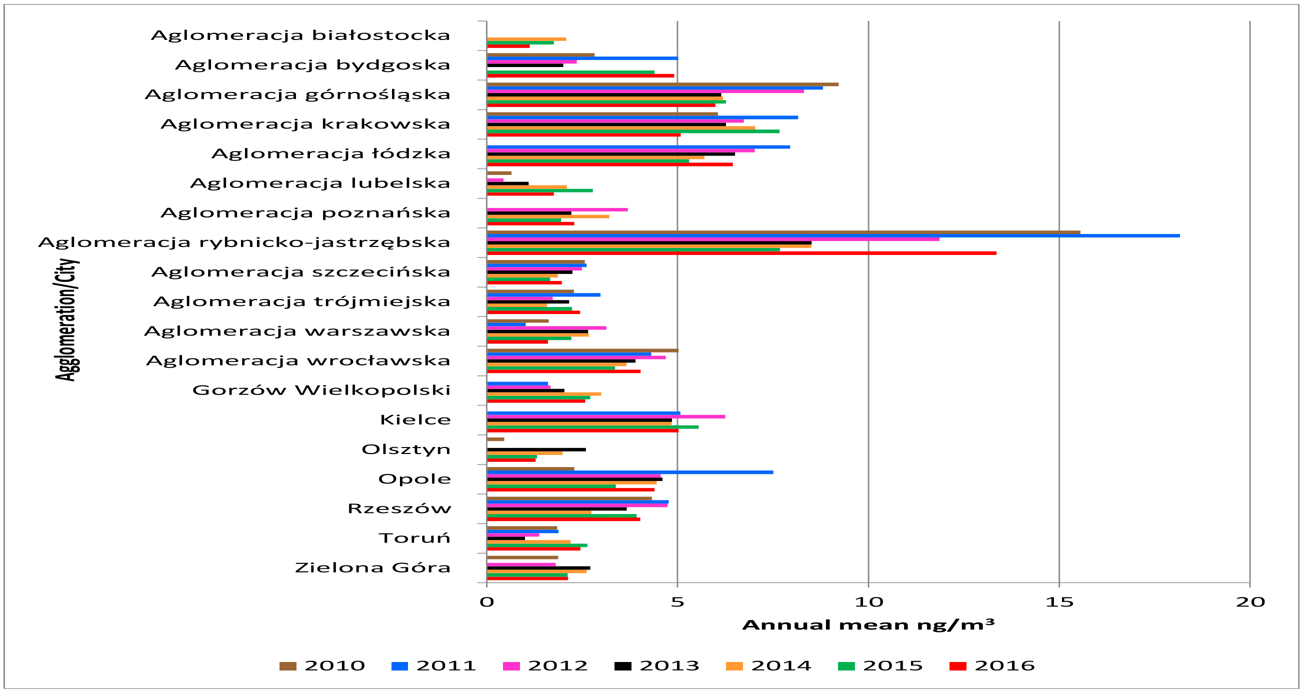


Source: Authors based on data from the Chief Inspectorate for Environmental Protection air quality portal.

Benzo[a]Pyrene - The main source of B[a]P in ambient air is residential wood burning. Other sources include commercial heating with wood or other biomass, motor-vehicle exhaust (especially from diesel engines), industrial emissions and forest fires. B[a]P concentrations are higher in Poland than in other EU countries (Statistics Poland, 2017). Annual average B[a]P concentrations across Polish cities and agglomerations in 2016 were greater than the EU Target Value (TV)[9] of 1 ng/m^3. Five agglomerations and one city had concentrations greater than 5 ng/m^3: Katowice, Rybnicko-jastrzębska, Krakow, Łódz, and Kielce (Figure 1.9). Unlike with PM_{10} and $PM_{2.5}$, there is no consistent pattern of declining concentrations of B[a]P across the country.

Figure 1.9. Average Annual Mean B[a]P Concentrations in Cities and Agglomerations Across Poland

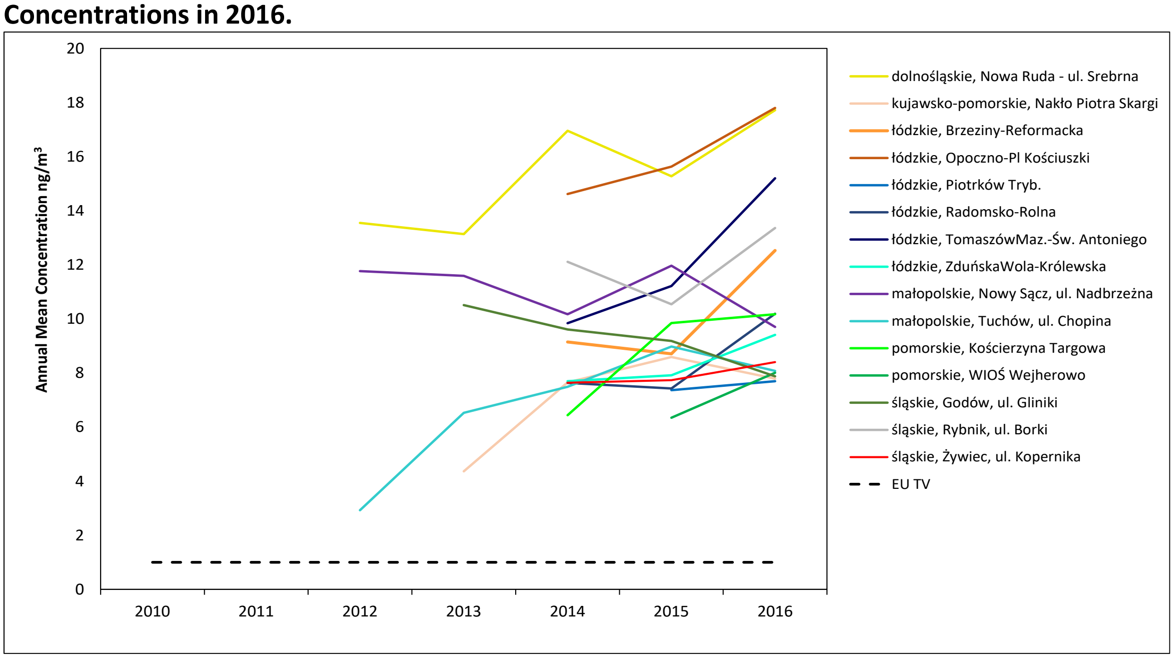
9 Under EU law, the obligation is to take all necessary measures not entailing disproportionate costs to ensure that a Target Value is attained, and so it is less strict than a Limit Value.



Source: Statistics Poland (2017)

Many sites are exceeding the EU Target Value by a factor of 10 over the last 3 to 4 years (Figure 1.10). Moreover, concentrations at many of the sites have actually increased. This suggests mitigation actions have either been absent or ineffective.

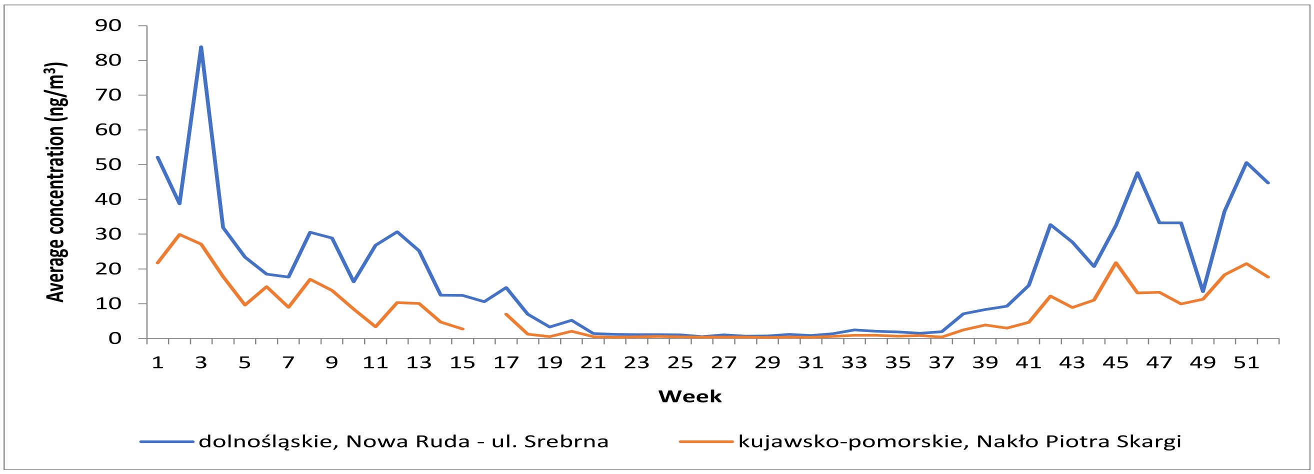
Figure 1.10. Trend in the Annual Mean Concentrations of B[a]P at the 15 Sites with the Highest Concentrations in 2016.



Source: Authors based on data from the Chief Inspectorate for Environmental Protection air quality portal.

As with particulate concentrations, B[a]P concentrations are driven by solid fuel combustion in small residential heating devices, and as such they show a strong seasonal influence, with the highest concentrations occurring during the winter (Figure 1.11). During summer months concentrations are below 1 ng/m^3 from early May into September.

Figure 1.11. Annual Trend in Weekly Concentrations of B[a]P at the Two Most Polluted Monitoring Sites.



Source: Authors based on data from the Chief Inspectorate for Environmental Protection air quality portal.

Summary

There is significantly less air pollution in Poland today when compared to the socialist period. Concerted and varied efforts by Poland during and after the transition period, including economic and environmental policy reforms, industrial restructuring and technological improvements, contributed to marked emission reductions in the widespread pollutants, particulate matter, SO_2 and NO_x.

Despite these efforts, elevated ambient concentrations of $PM_{2.5}$, PM_{10}, and B[a]P remain a challenge in Poland. $PM_{2.5}$ is the more important particulate and is more damaging to health than PM_{10}. However, monitoring of $PM_{2.5}$ in Poland is more recent.

Exceedances are seen across the country in urban areas, but the most widespread exceedances of the EU air quality standards for the above pollutants are seen in the voivodeships of śląskie and neighboring małopolskie in the south-western part of the country. The voivodeships of małopolskie and łódzkie experienced the two highest numbers of days of exceedances of the PM_{10} daily EU LV and the highest measured concentrations of B[a]P.

Trends show that the highest concentrations for all three of the above pollutants occur during the winter, coinciding with peak heating demand. Burning of highly polluting solid fuels for in small combustion devices (i.e., boiler and individual stoves in households) is the leading source of particulate matter pollution. For $PM_{2.5}$ and PM_{10}, heating is the key driver for elevated emissions, but transport, industry, and secondary pollutant emissions may also contribute to ambient particulate matter concentrations. During the summer months concentrations of B[a]P were found to be extremely low at the two sites with the highest winter concentrations. This suggests that for this pollutant, residential combustion of biomass for heating purposes is the overriding emission source.

Nitrogen dioxide is only of concern in four cities (Warsaw, Krakow, Katowice and Wroclaw) and temporal trends show that traffic is the main emission source for this pollutant. Elevated ozone concentrations are not a significant problem in Poland. In 2016, ozone exceedances were limited to 6 sites and the numbers of days of exceedances were close to the allowable number. There have been no exceedances of the annual average EU LV for sulfur dioxide since 2012.

Chapter 2. Economic Cost of Ambient Air Pollution in Poland

This chapter focuses on estimation of the health burden (i.e., mortality and morbidity), and cost of ambient air pollution ($PM_{2.5}$), based upon available information on population exposure, background health statistics and economic data by each voivodeship in Poland.

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.[10] 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. The rate of cardiovascular diseases in Poland (about 46% of the total deaths in 2016) is lower than in Eastern Europe, but higher than in Western Europe (GBD 2016). These diseases mostly affect people older than 65 years of age (65% of total deaths occur after 70 years of age in Poland). Thus, this subgroup of population should be the focus of specific mitigation measures to reduce the impact attributed of air pollution in Poland.

In recent years, several global and international studies have provided estimates of annual mortality in Poland due to ambient $PM_{2.5}$ pollution. Some these estimates come from the European Environment Agency (EEA) report of 2018 (44,500 deaths), and the Global Burden of Disease reports of 2016 (26,000 deaths) and 2017 (21,000 deaths).[11] It is pertinent to note that all the studies, including the current study, apply techniques that are included in the menu of approved methodologies provided by the WHO Health Risks of Air Pollution in Europe (HRAPIE) project (WHO, 2013).

In 2018, Poland's Ministry of Entrepreneurship and Technology published a report that estimated 18,990 deaths attributed to residential heating and communal sectors in 2016 (Adamkiewicz. 2018).[12] This study examined two sources of ambient air pollution using an adjusted ExternE methodology developed for the energy sector.

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10 As recommended by WHO, health risk factors are divided into three groups: metabolic, behavioral and environmental (see http://ghdx.healthdata.org/gbd-results-tool). Other risk factors for cardiovascular and pulmonary disease include tobacco smoking, alcohol and drug use, dietary risks, high blood pressure, etc.

11 Available through: http://ghdx.healthdata.org/gbd-results-tool

12 https://www.mpit.gov.pl/media/61515/Raport__zewnetrzne_koszty_zdrowotne_emisji_zanieczyszczen_powietrza_z_sektora_bytowo_komunalnego.pdf

The current study estimates that 25,280 - 44,811 deaths were caused by ambient $PM_{2.5}$ pollution in Poland in 2016. The analysis applied two methodologies: (i) the approach from the 2016 Global Burden of Disease study; and (ii) the approach used by the EEA in their 2018 study. GBD studies analyze the health risks attributable to environmental factors, for different years, for most countries by linking environmental factors with the burden of disease attributable to them.[13] Consistent with the GBD methodology, the analysis in this chapter applies a conservative approach by calculating premature, age-specific mortality from five diseases - ischemic heart disease, stroke, COPD, lung cancer, lower respiratory illness – that are directly linked to $PM_{2.5}$ pollution. By contrast, the EEA approach calculates all-cause or non-accidental mortality (i.e., all deaths excluding poisoning, suicide and war), and assumes a linear relationship between mortality and $PM_{2.5}$ concentration for population above age 30.

The morbidity health burden is estimated in this report using HRAPIE recommended methodology (WHO, 2013) that focuses on acute bronchitis for children, chronic bronchitis for adults, cardiovascular and respiratory hospital admissions and lost work days caused by PM air pollution.

Analytical Approach to Damage Estimation

1. Estimate *population exposure* to particulate matter pollution in terms of number of people exposed to specific level(s) of concentration.
2. Calculate the *health burden*, premature death (mortality) or disability (morbidity) 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.[14] [15]
3. Estimate the *economic value* of this health burden in monetary terms. Two approaches, the welfare-based approach and the income-based approach are used.

Ambient Air Quality and Exposed Population in Poland

Ambient air quality monitoring data in 2016 showed that the highest concentrations of ambient air pollution occurred in wielkopolskie, małopolskie and śląskie voivodeships, where the

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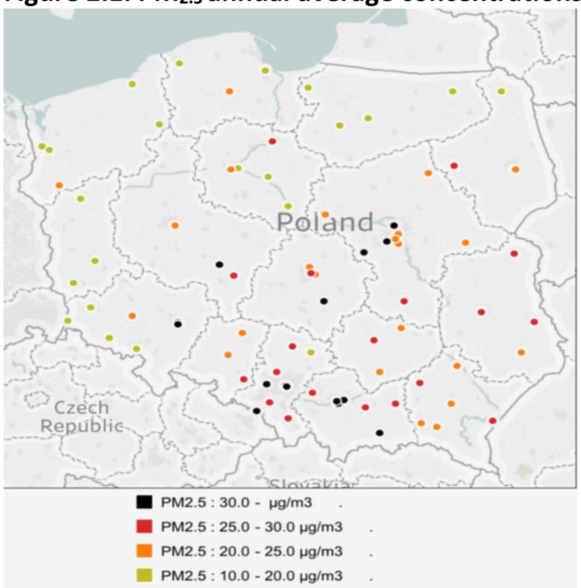
13 The methodology of the GBD analysis can be found at: http://www.healthdata.org/gbd/publications
14 Relative risk (RR) is defined as the ratio of the probability of a health outcome, namely premature death (mortality) or disability from a disease, occurring in an exposed group to the probability of it occurring in a non-exposed group.
15 PAF 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 limits15. (Adapted from WHO definition at www.who.int/healthinfo/global_burden_disease/metrics_paf/en/ (accessed on 2/13/2018).)

average annual population-weighted $PM_{2.5}$ concentration was above the EU Limit Value of 25 μg/m^3. In lubelskie, łódzkie, opolskie, dolnośląskie, mazowieckie, podkarpackie, and świętokrzyskie voivodeships the average annual $PM_{2.5}$ population-weighted concentration was 21-24 μg/m^3. Annual average concentrations of $PM_{2.5}$ by agglomeration in Poland in 2015 are shown in Figure 2.1, while the high and low $PM_{2.5}$ annual average concentrations for 2016 and the population in each voivodeship are shown in Table 2.1.

Figure 2.1. $PM_{2.5}$ annual average concentrations by agglomeration in Poland (2015)



Source: https://www.eea.europa.eu/data-and-maps/dashboards/air-quality-statistics

Table 2.1. PM2.5 Annual Average Concentration and Exposed Population in Each Voivodeship

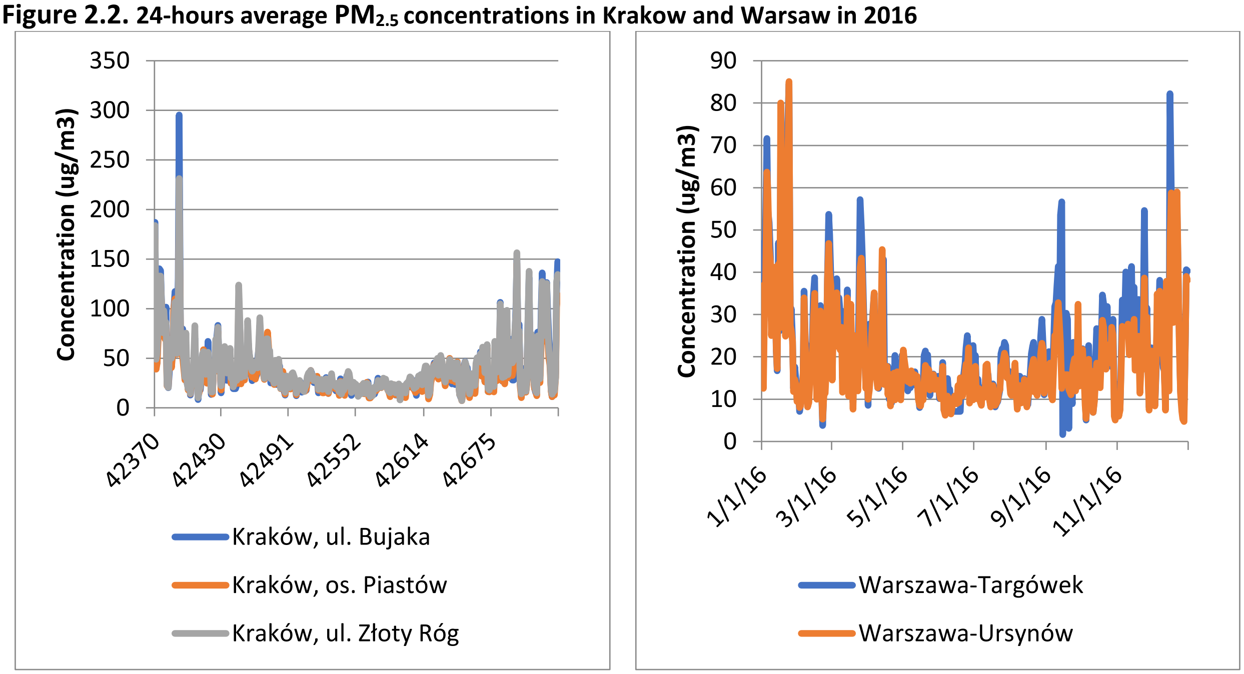
Voivodeship	$PM_{2.5}$ μg/m^3		Population (thousands)
	Low	High	
dolnośląskie	21	25	2,904
kujawsko-pomorskie	17	20	2,084
lubelskie	21	21	2,133
lubuskie	17	22	1,017
łódzkie	22	22	2,485
małopolskie	25	32	3,382
mazowieckie	22	24	5,366
opolskie	22	22	993
podkarpackie	23	23	2,128
podlaskie	20	20	1,187
pomorskie	15	15	2,316
śląskie	27	31	4,559
świętokrzyskie	24	24	1,253
warmińsko-mazurskie	16	16	1,436

wielkopolskie	25	28	3,482
zachodniopomorskie	14	16	1,708

Source: Inspekcja Ochrony Środowiska, 2017; Statistical Yearbook of the Regions - Poland 2017[16].

During winter months, 24-hour $PM_{2.5}$ concentrations were often extremely high, leading to deaths and injuries from smog inhalation. These extremely high 24-hour $PM_{2.5}$ concentrations were recorded in Krakow (3 monitoring stations) and Warsaw (2 monitoring stations) in 2016. In Krakow, average concentrations during the three winter months were double the average concentrations of the nine remaining months (39 µg/m^3 for the winter and 19 µg/m^3 for the rest of the year) and in Warsaw 60% higher (winter, 25; rest of year,15 µg/m^3). The 24-hour $PM_{2.5}$ concentrations in Krakow were higher than 100 µg/m^3 for about 15 winter days, and in Warsaw they were higher than 50 µg/m^3 for 10-20 days. Ambient particulate matter concentrations at these and some other stations in Poland consistently exceeded the EU PM_{10} annual limit value (40 µg/m^3) (EEA 2017) (Figure 2.2).

Figure 2.2. 24-hours average $PM_{2.5}$ concentrations in Krakow and Warsaw in 2016



Source: Voivodeship Inspectorate for Environmental Protection in Krakow, 2018.

16 http://stat.gov.pl/en/topics/statistical-yearbooks/statistical-yearbooks/statistical-yearbook-of-the-regions-poland-2017,4,12.html

Estimation of Health Burden of Exposure to Ambient Air Pollution

This section estimates mortality and morbidity attributed to exposure to ambient air pollution (AAP) from all sources in Poland.

Mortality from AAP is calculated using two methods that are approved by the HRAPIE project (WHO, 2013):

Method 1. This method applies the GBD 2016 methodology and uses population exposure to estimate the cause-specific mortality associated with ambient air pollution, including mortality risk by age group of the population attributable fractions of:

- Ischemic heart disease, IHD (population above 30 years of age)[17]
- Stroke (population above 30 years of age)
- Lung cancer, LC (population above 30 years of age)
- Chronic obstructive pulmonary disease, COPD (population above 30 years of age)
- Lower respiratory illness, LRI (all ages)

Method 2 - For comparative purposes, this section also provides an estimate that is based on all-cause (natural) mortality in ages above 30, attributable to ambient air pollution, as provided in EEA (2018). This method assumes a linearly increased risk of mortality per increase of $PM_{2.5}$ concentration.

As noted from Table 2.2, Method 2 provides a significantly higher mortality estimate than Method 1. However, Method 2, unlike Method 1, is not recommended for use in cost-benefit analysis (WHO 2013). Given that it is a goal of this report to provide a cost-benefit analysis (chapter 4) of alternative interventions to address ambient air pollution in the most polluted voivodeships in Poland, this report does not pursue further analysis with the results of Method 2 beyond this section of this report. The mortality estimate obtained from Method 2 may therefore be considered as an upper bound or less conservative estimate of AAP-related mortality at a national level that could serve for reference or illustrative purposes. Further economic analysis in this report will be conducted using the more conservative estimates obtained from Method 1.

17 Statistical data on deaths by cause on Poland is consistent with the GBD 2016 database, except there is a significant discrepancy in estimating the burden of IHD. Although the total burden of cardiovascular disease is consistent in the national and global databases, the IHD burden is about three times lower in the national database. This study used an average between the national reported and the global estimated IHD mortality.

The estimated annual mortality attributed to air pollution in 2016 is presented in Table 2.2, disaggregated by voivodeship. The rate of mortality attributed to ambient air pollution (individual health risk attributed to air pollution) is estimated at 66 per 100,000 on average in Poland (Method 1). In the five voivodeships (dolnośląskie, łódzkie, małopolskie, śląskie, and świętokrzyskie) rate of mortality is estimated at 71-82 per 100,000. At the same time, total mortality attributed to ambient air pollution (population health risk attributed to ambient air pollution) is highest in śląskie, mazowieckie, małopolskie, and wielkopolskie voivodeships (Figure 2.3). Interventions to reduce ambient air pollution (AAP) undertaken in these voivodeships will potentially reduce the health burden the most. On average, premature death attributed to ambient air pollution (AAP) accounts for approximately 6.4% of the total mortality in Poland in 2016.

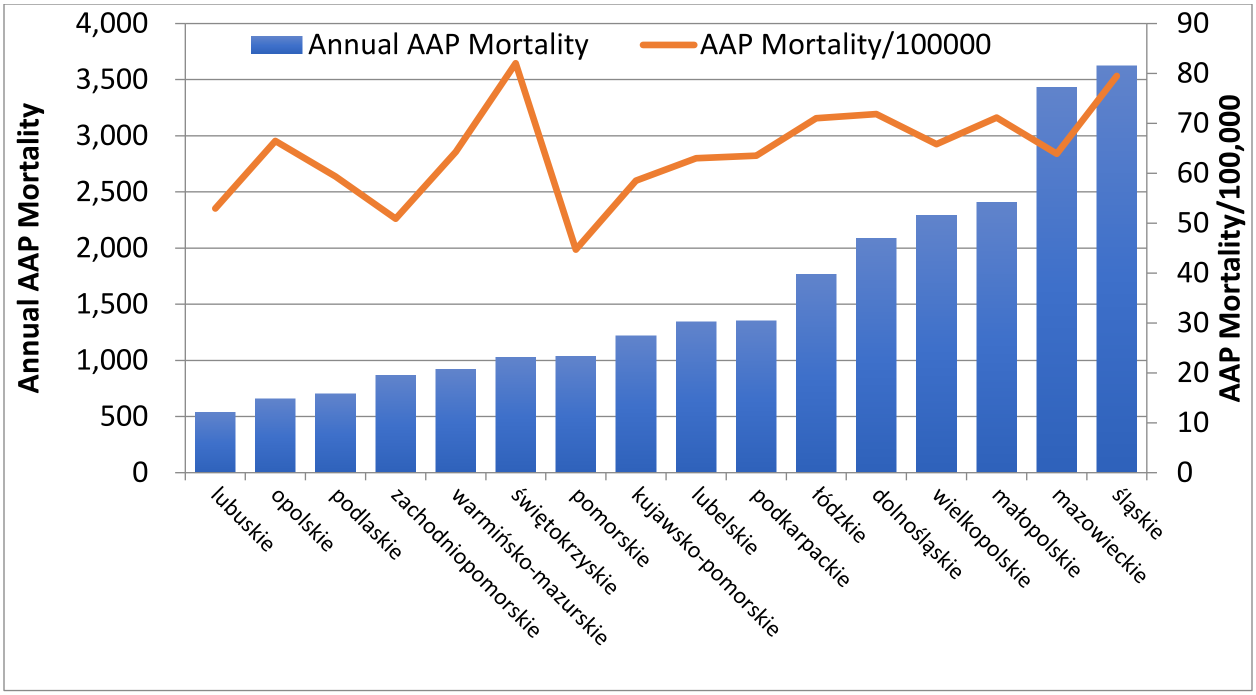
Table 2.2. Annual mortality attributed to ambient air pollution in Poland in 2016

Location	**0-4**	**5 - 14**	**15-49**	**50-69**	**70+**	**Total, method 1**	**Total, method 2**
dolnośląskie	0.9	0.1	85	723	1,278	2,086	3,456
kujawsko-pomorskie	0.4	0.1	51	413	755	1,220	1,832
lubelskie	0.5	0.1	57	448	839	1,344	2,496
lubuskie	0.1	0.0	23	184	332	539	860
łódzkie	0.9	0.1	72	582	1,111	1,766	3,549
małopolskie	0.8	0.1	95	834	1,477	2,407	4,090
mazowieckie	1.8	0.3	141	1,123	2,165	3,430	6,218
opolskie	0.3	0.0	28	216	416	660	1,216
podkarpackie	0.4	0.1	57	473	822	1,352	2,342
podlaskie	0.3	0.0	29	234	441	705	1,264
pomorskie	0.5	0.1	43	330	662	1,035	1,616
śląskie	1.2	0.2	142	1,258	2,223	3,625	7,324
świętokrzyskie	0.2	0.0	44	362	622	1,028	1,816
warmińsko-mazurskie	0.0	0.0	41	352	530	923	1,141
wielkopolskie	1.2	0.2	88	780	1,423	2,292	4,336
zachodniopomorskie	0.3	0.0	37	279	553	869	1,255
Poland	9.7	1.5	1,032	8,589	15,648	25,280	44,811

Source: Estimated by authors

Total mortality or population health risk by voivodeship is illustrated in Figure 2.3. Mazowieckie and śląskie have the highest absolute levels of mortality although świętokrzyskie has the highest rate of individual risk.

Figure 2.3. Individual risk (rate of AAP mortality) and population risk (total AAP mortality) attributed to ambient air pollution in Poland in 2016



Source: Estimated by authors using Method 1.

Morbidity from AAP is estimated as the population attributable fractions of:

- Bronchitis prevalence for children 6-12
- Chronic bronchitis (including chronic obstructive pulmonary disease or COPD) incidence for adults above 18
- Hospital admissions cardiovascular (CV)
- Hospital admissions respiratory
- Lost work days

The estimated annual cases of morbidity burden attributed to air pollution in Poland are presented by voivodeship and by disease in Table 2.3.

Table 2.3. Estimated annual cases of morbidity end-points attributed to AAP

Location	Bronchitis in children	Chronic bronchitis in adults	CV hospital admissions	Respiratory hospital admissions	Lost work days
dolnośląskie	16,027	3,510	447	1,662	1,216
kujawsko-pomorskie	11,000	2,119	218	1,003	672
lubelskie	10,897	3,276	314	1,026	631
lubuskie	5,055	1,310	90	390	271
łódzkie	16,325	4,926	298	1,411	1,676
małopolskie	21,939	4,459	635	2,363	1,542
mazowieckie	29,772	5,834	803	2,334	2,162

opolskie	5,695	1,193	151	525	384
podkarpackie	10,940	2,495	259	948	875
podlaskie	4,773	1,215	117	578	262
pomorskie	9,679	2,060	177	607	638
śląskie	31,751	7,742	867	2,497	3,069
świętokrzyskie	6,561	1,675	199	743	614
warmińsko-mazurskie	6,382	1,359	113	788	361
wielkopolskie	19,396	4,318	458	1,833	2,092
zachodniopomorskie	7,119	1,569	149	433	382
Poland	213,313	49,061	5,295	19,139	16,847

Source: Estimated by authors

In Poland, AAP is associated with 23% of the annual burden of bronchitis in children and 33% of the annual burden of chronic bronchitis in adults. The highest burden is in mazowieckie and śląskie voivodeships. AAP is also associated with 2% of the CV, 4.5% of respiratory hospital admissions and 8% of the total lost workdays. The highest burden is in wielkopolskie, mazowieckie, śląskie, łódzkie, and małopolskie voivodeships. In winter when ambient air pollution is elevated, morbidity costs associated with AAP are highest. During this period, there is a sharp increase of cardiovascular and respiratory hospital admissions and respiratory infections. This could result in significantly increased pressure on the local health care system (hospitals, clinics, doctors, etc.) and loss of productivity attributable to AAP. Based on seasonal data on daily average ambient concentrations of $PM_{2.5}$ and background hospital admissions, the daily burden of morbidity attributable to short-term air pollution is at least 1.6-2 times higher in winter months than in other seasons.

Economic cost of exposure to Ambient Air Pollution in Poland

This section estimates, in monetary terms, the health burden that was assessed in the previous section. Two approaches, the welfare-based approach and the income-based approach (foregone output), are used to quantify the economic burden associated with AAP mortality. The welfare-based cost of mortality is calculated by multiplying the estimated number of premature deaths by the value of a statistical life (VSL) in each voivodeship. The VSL represents an aggregate of individuals' willingness to pay (WTP) for marginal reductions in their mortality risks, and thus, estimates welfare losses associated with a statistical case of mortality. Income-based cost of mortality estimates a foregone output attributed to an age-weighted mortality case in each voivodeship. Thus, the income-based cost represents actual income loss due to death of a person in a labor force. Cost of Illness (COI) approach is used to valuate morbidity. Cost of Illness combines treatment cost and cost of time lost due to each morbidity case on average. Annex B presents the methodology for the mortality and morbidity valuation used in this study.

Cost of mortality attributed to AAP

Using welfare-based mortality valuation, the annual cost of mortality caused by AAP in Poland is estimated at US$30-39 Billion (Table 2.4). The annual cost is highest in mazowieckie and śląskie voivodeships. If mortality is valued using Forgone Output approach, the annual cost of AAP is estimated at about US$1 Billion.

Table 2.4. Estimated annual cost of mortality from AAP in Poland

	Mortality/VSL US$ Bn.		Mortality/Forgone Output US$ Bn.
	Low	High	
dolnośląskie	2.72	3.43	0.12
kujawsko-pomorskie	1.16	1.66	0.06
lubelskie	1.08	1.65	0.07
lubuskie	0.52	0.74	0.03
łódzkie	1.92	2.61	0.10
małopolskie	2.52	3.47	0.13
mazowieckie	6.35	6.96	0.27
opolskie	0.63	0.90	0.03
podkarpackie	1.12	1.69	0.07
podlaskie	0.59	0.89	0.04
pomorskie	1.16	1.55	0.06
śląskie	4.42	5.72	0.20
świętokrzyskie	0.87	1.31	0.05
warmińsko-mazurskie	0.85	1.24	0.04
wielkopolskie	2.90	3.70	0.13
zachodniopomorskie	0.86	1.21	0.04
Total for Poland	29.67	38.74	1.46

Source: estimated by authors.

Cost of morbidity attributed to AAP

The estimated annual cost of morbidity attributed to air pollution is presented for each voivodeship in Table 2.5 and Figure 2.4. Lost workdays account for about 75% of the total morbidity cost. Chronic bronchitis in adults and bronchitis in children account for 16% and 6% of the total morbidity cost respectively. The highest total annual morbidity costs are in mazowieckie and śląskie voivodeships (Table 2.5).

Table 2.5. The estimated annual morbidity cost attributed to AAP (US$ Million)

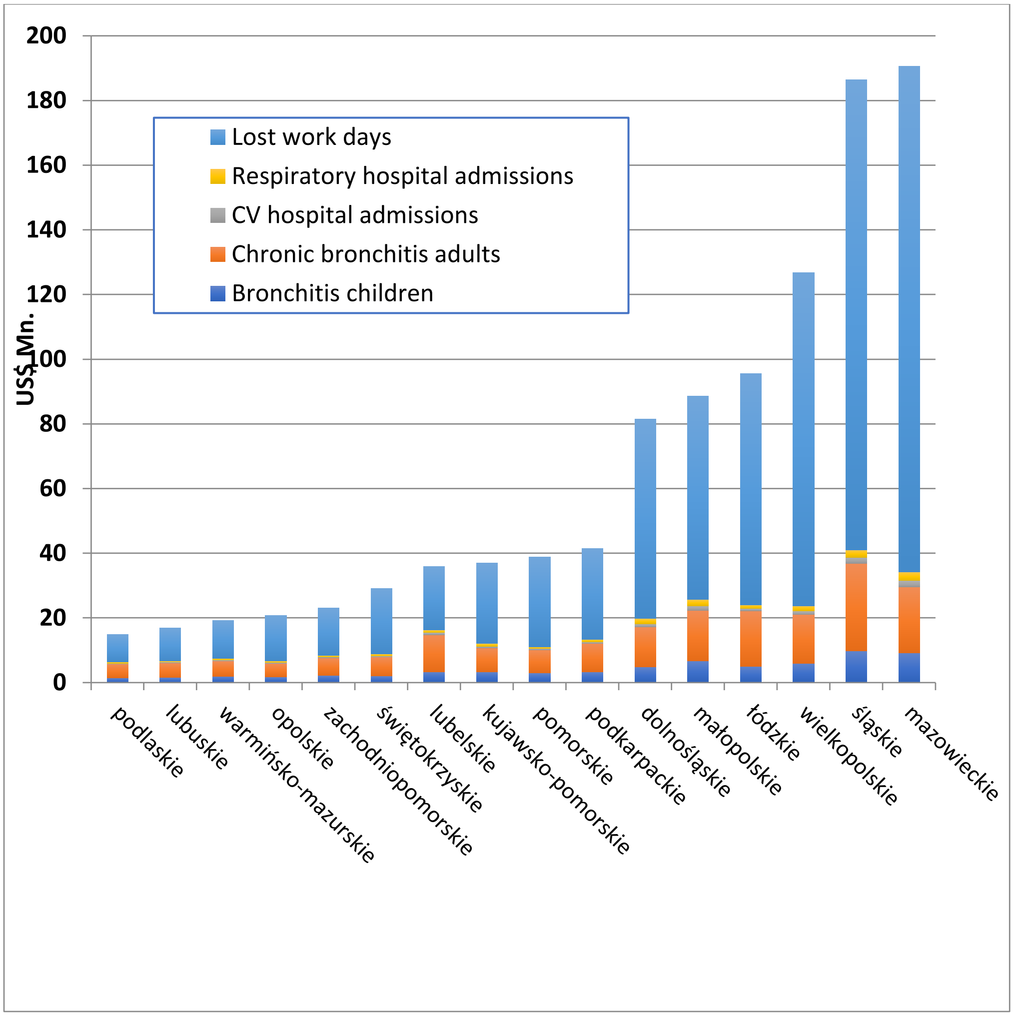
	Bronchitis children	Chronic bronchitis adults	CV hospital admissions	Respiratory hospital admissions	Lost work days	Total

dolnośląskie	4.9	12.3	1.0	1.6	61.7	81.5
kujawsko-pomorskie	3.4	7.4	0.5	0.8	24.9	36.9
lubelskie	3.3	11.4	0.7	0.8	19.7	35.9
lubuskie	1.5	4.6	0.2	0.3	10.3	16.9
łódzkie	5.0	17.2	0.7	1.2	71.4	95.5
małopolskie	6.7	15.6	1.4	2.0	63.0	88.6
mazowieckie	9.1	20.4	2.0	2.7	156.4	190.6
opolskie	1.7	4.2	0.3	0.4	14.2	20.8
podkarpackie	3.4	8.7	0.6	0.7	28.2	41.5
podlaskie	1.5	4.2	0.2	0.4	8.5	14.9
pomorskie	3.0	7.2	0.4	0.5	27.8	38.9
śląskie	9.7	27.0	2.0	2.3	145.4	186.4
świętokrzyskie	2.0	5.9	0.4	0.6	20.2	29.1
warmińsko-mazurskie	2.0	4.7	0.2	0.6	11.7	19.2
wielkopolskie	5.9	15.1	1.0	1.7	103.0	126.8
zachodniopomorskie	2.2	5.5	0.3	0.4	14.7	23.1
Poland	65.4	171.4	12.0	16.9	781.2	1047

Source: estimated by authors

Expressed on a per capita basis, that reflects the annual AAP burden on an average person, the annual morbidity cost is highest in śląskie (us$41/person) and łódzkie(us$38/person), voivodeships. The cost is also high in mazowieckie, wielkopolskie, małopolskie and dolnośląskie voivodeships (us$26-36/person).

Figure 2.4. The estimated annual morbidity cost attributed to AAP



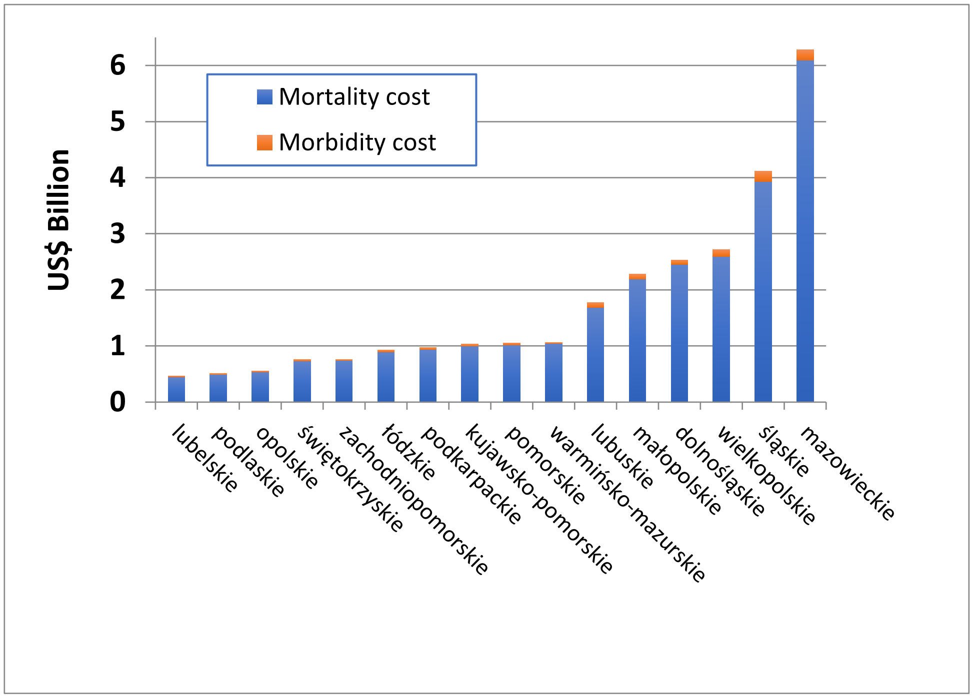
Source: estimated by authors

Total Economic Cost of health burden attributed to Ambient Air Pollution

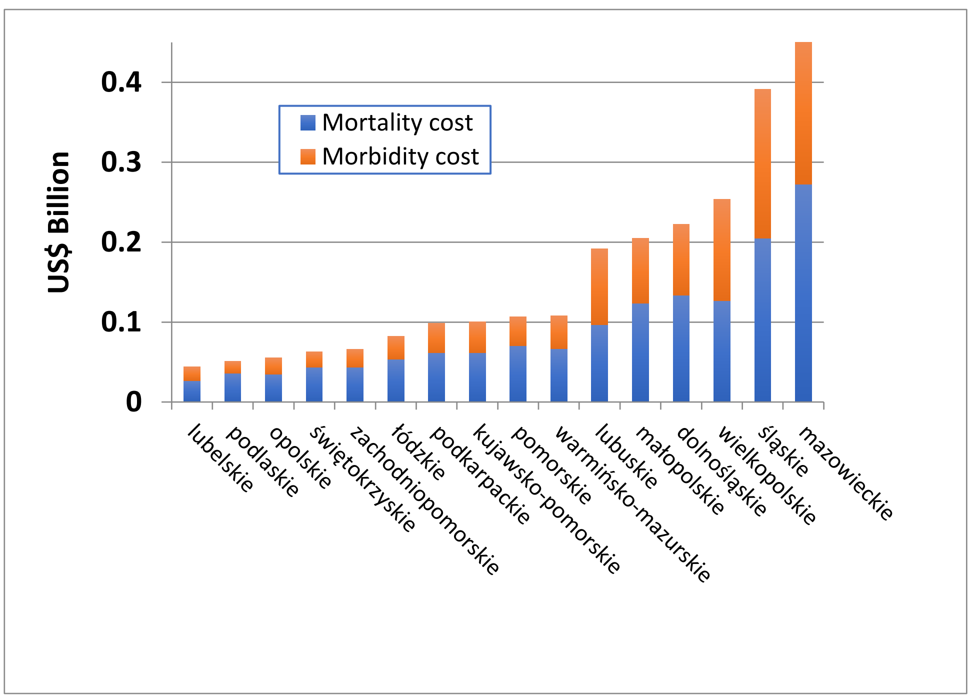
Using welfare-based mortality valuation, the total annual cost of mortality and morbidity related to AAP in Poland is estimated at US$31-40 Billion, equivalent to 6.4-8.3% of Poland's GDP in 2016. Total annual cost of AAP pollution by voivodeship is presented in Figure 2.5 and in Table 2.6. The total annual cost is highest in mazowieckie and śląskie voivodeships. If mortality is valued using Forgone Output approach, the total annual cost of AAP is estimated at about US$3 Billion, equivalent to 0.6% of Poland's GDP in 2016. With Foregone Output valuation approach to mortality, the total annual cost of morbidity accounts for about 40% of the total AAP cost.

Figure 2.5. Total annual AAP Cost, US$ Billion

1. Voivodeship's VSL for mortality valuation



2. Forgone Output for mortality valuation



Source: estimated by authors

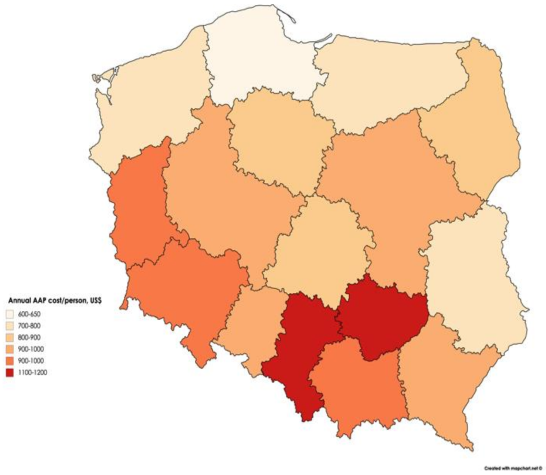
Table 2.6. Estimated total annual cost of AAP in Poland

	Mortality/VSL US$ Bn.		Mortality/Forgone Output US$ Bn.	Morbidity/COI US$ Bn.
	Low	High		
dolnośląskie	2.72	3.43	0.12	0.08
kujawsko-pomorskie	1.16	1.66	0.06	0.04
lubelskie	1.08	1.65	0.07	0.04
lubuskie	0.52	0.74	0.03	0.02
łódzkie	1.92	2.61	0.10	0.10
małopolskie	2.52	3.47	0.13	0.09
mazowieckie	6.35	6.96	0.27	0.19
opolskie	0.63	0.90	0.03	0.02
podkarpackie	1.12	1.69	0.07	0.04
podlaskie	0.59	0.89	0.04	0.01
pomorskie	1.16	1.55	0.06	0.04
śląskie	4.42	5.72	0.20	0.19
świętokrzyskie	0.87	1.31	0.05	0.03
warmińsko-mazurskie	0.85	1.24	0.04	0.02
wielkopolskie	2.90	3.70	0.13	0.13
zachodniopomorskie	0.86	1.21	0.04	0.02
Total for Poland	29.67	38.74	1.46	1.05

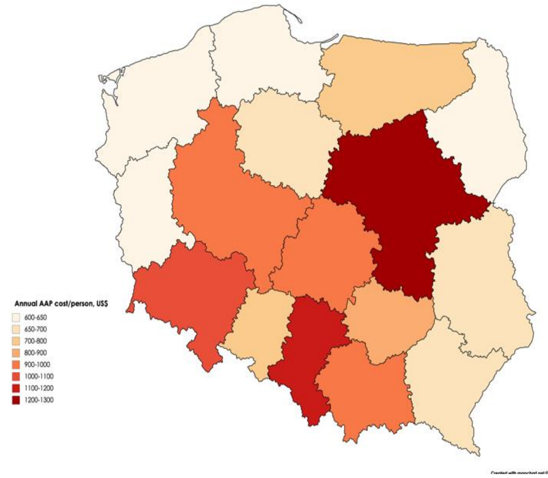
Source: estimated by authors.

Voivodeships in the south and southwest of Poland bear the most significant total annual cost on a per capita basis. Śląskie and dolnośląskie, voivodeships with a cost of AAP in the range of US$1100-1200 per person annually, have the highest costs if mortality is valued based on the average VSL for all of Poland. However, mazowieckie and śląskie voivodeships emerge with the highest annual AAP cost per person (US$1,150-1,300) if mortality is valued based on the respective VSL of each voivodeship, reflecting higher welfare loss per case of mortality in the voivodeships with relatively higher GDP per capita (Figure 2.6).

Figure 2.6. **Cost of Ambient Air Pollution cost per capita, US$**



VSL Poland average for mortality valuation



VSL voivodeships for mortality valuation

Source: compiled by authors

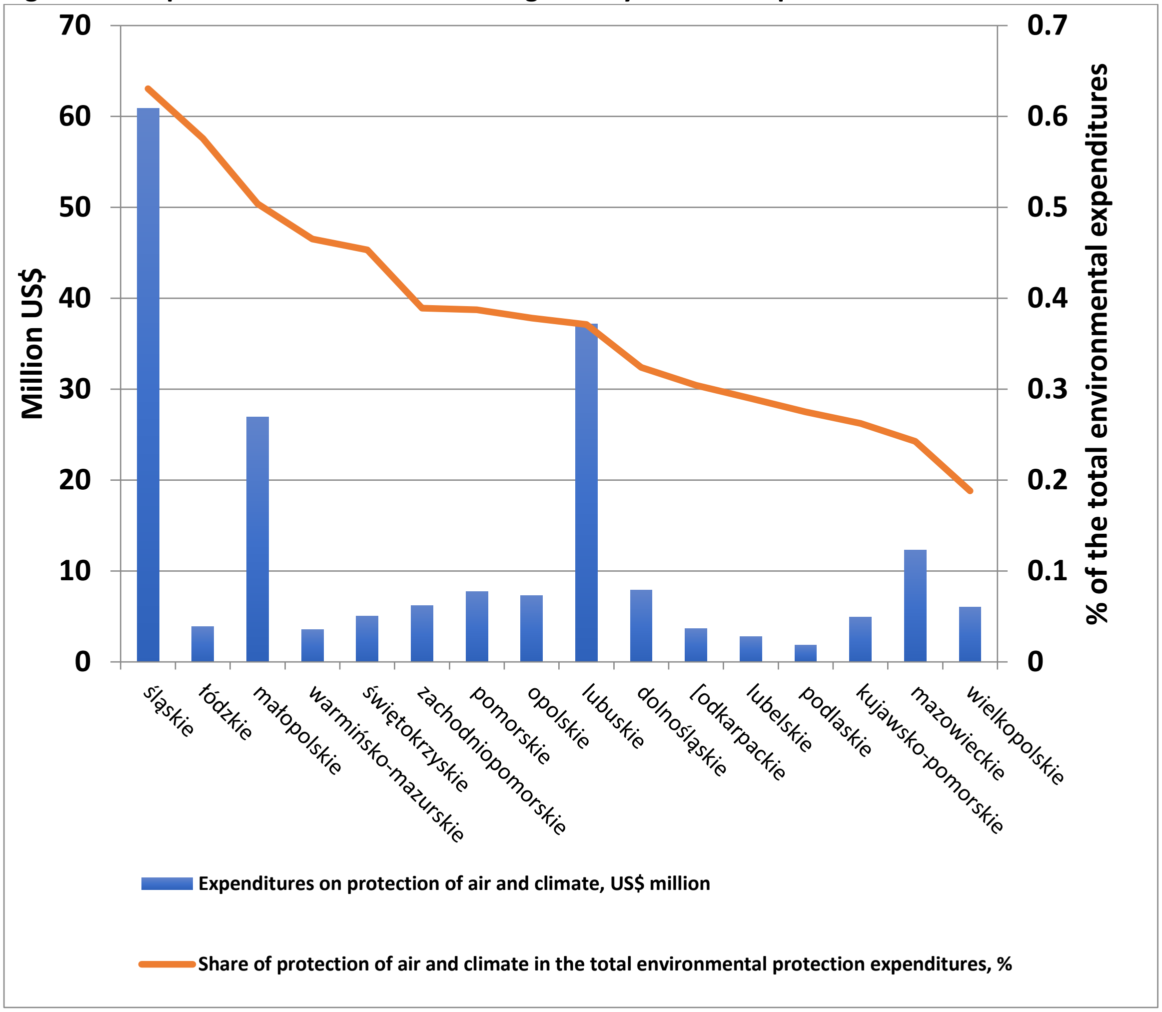
Healthcare and Air Protection Expenditures

On average, the cost of AAP is estimated at US$35 billion. This value exceeds total current expenditures on health care (both public and private) in 2015 (US$30 billion), as reported in "Health and Health care in 2016 Tables" for Poland.[18] The total annual budget of the National Health Fund (the publicly funded health care system in Poland) is about US$18 billion in 2016.[19]

Although some voivodeships are currently doing their best to tackle the problem, not all of them are spending sums that are commensurate with the issue's seriousness. Śląskie voivodeship, with one of the highest AAP mortality cost (VSL based) per capita, has the highest expenditures on air and climate programs in 2016. However, małopolskie voivodeship spends less than half of what śląskie does on half on air and climate programs, and mazowieckie voivodeship's spending, which is 10 percent of its total environmental expenditures, amounts to less than one fifth of śląskie's although both małopolskie and mazowieckie are among the voivodeships with the highest AAP health costs (Figure 2.7). What does hold true is that voivodeships with higher AAP costs (e.g. śląskie and mazowieckie) have higher local health care expenditures (Figure 2.8).

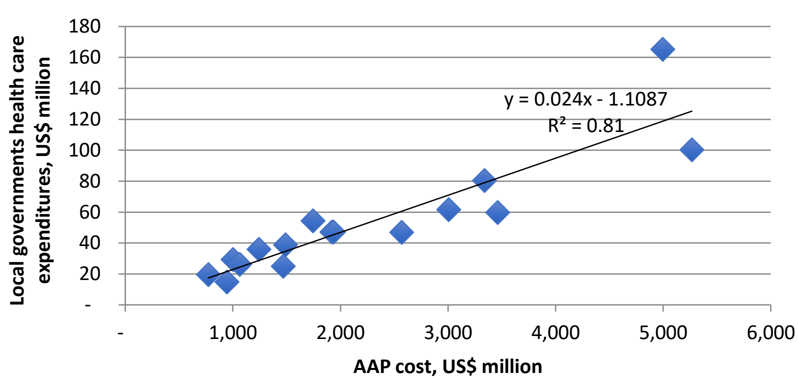
18 For 2015 current health care expenditures estimated in https://stat.gov.pl/en/topics/health/. The estimate for 2016 is not available at the time of the study.. Official exchange rate in 2015 US$1: PLN3.8; in 2016 US$1:PLN3.9 (WDI, 2018)
19 http://www.nfz.gov.pl/bip/finanse-nfz/

Figure 2.7. Expenses of Air and Climate Programs by Voivodeship in 2016



Source: Statistical Yearbook of the Regions - Poland 2017

Figure 2.8. The estimated total annual AAP cost and local health care expenditures by voivodeship in 2016 (US$)



Source: estimated by authors using data from Statistical Yearbook of the Regions - Poland 2017 and AAP cost from this report

Summary

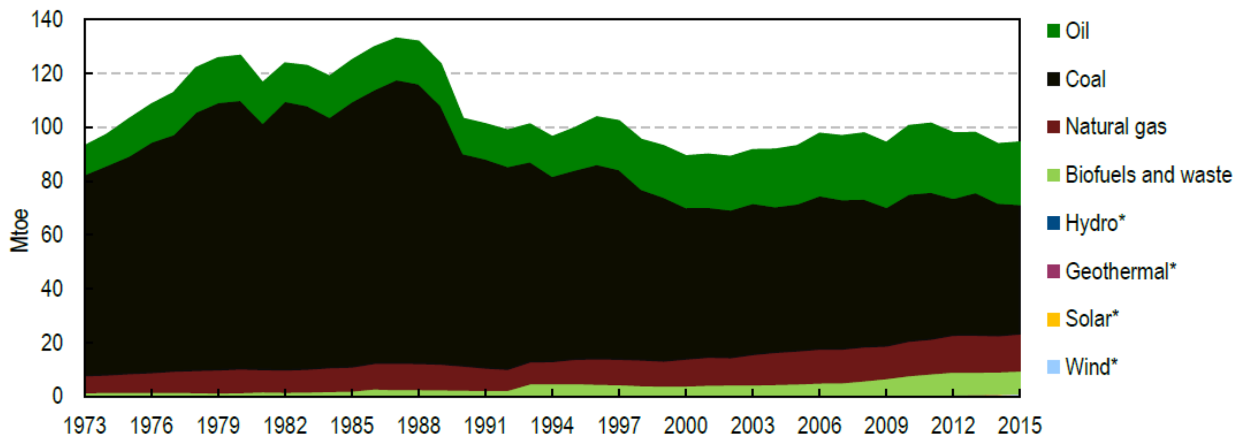
If valued with a welfare-based approach, the economic burden (mortality and morbidity) is estimated in the range US$31-40 billion, equivalent to 6.4-8.3% of GDP in 2016 in Poland. And even this figure cannot fully capture the extent of the toll that air pollution takes: at least 25,000 deaths every year.

All of these costs arise as a result of one pollutant, $PM_{2.5}$, and, as will be shown in the next chapter, the vast majority of $PM_{2.5}$ emissions come from the residential sector. This in one sense exacerbates the problem, because the result is that concentrations are particularly high during one portion of the year, which means that even residents in areas with relatively low average $PM_{2.5}$ concentration have the potential to be exposed to high levels at least some part of the year, which in turn is likely to cause health effects. Future chapters will show that interventions to reduce polluting emissions from households are relatively economically-effective when seen in the context of the burden that AAP places upon Poland's health system.

Chapter 3. Sources of Air Pollution in Poland

At the root of Poland's air quality problems is the extensive use of coal as a source of residential and commercial heating, and in power production and industry (Figure 3.1). The residential and industrial sectors account for the largest shares of energy consumption at 29% and 29.9% respectively, followed by the transport (24%) and commercial (17.2%) sectors (IEA, 2017). There has been a significant reduction in the total quantity of coal used since socialist times, and there has been some increase in the use of natural gas. But coal, which is generally a more highly polluting energy source, is still dominant.

Figure 3.1. Primary energy consumption [Mtoe] by source in Poland 1973 – 2015



* Negligible.

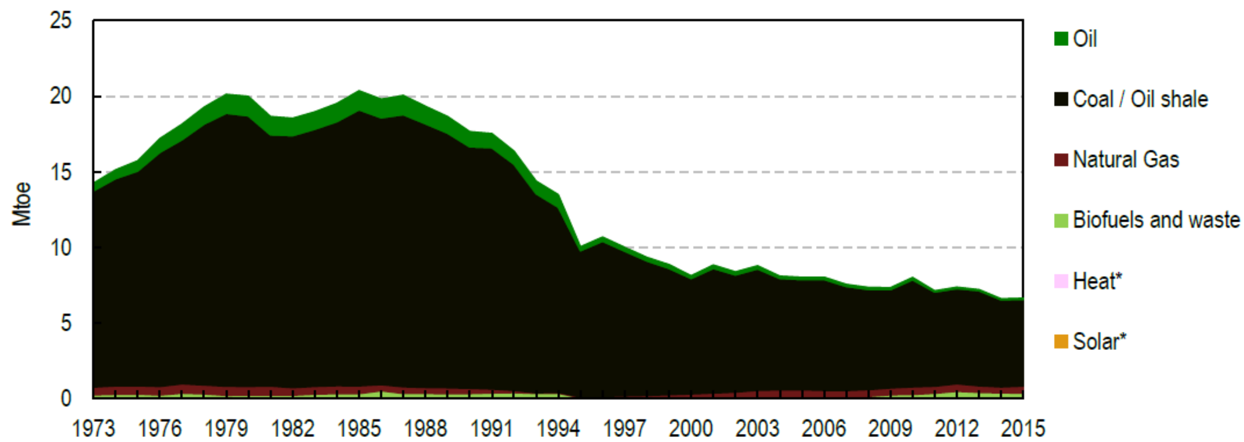
Note: Data are estimated for 2015.

. Source: IEA 2017.

Residential Heating

Coal used for household heating makes up one-third of total energy consumption in the residential sector (IEA, 2017). The residential sector is the largest consumer of heat, accounting for 71% of total heat consumption in Poland (IEA, 2017), and coal is the dominant heat source, as seen in Figure 3.2.

Figure 3.2. Heat Production [Mtoe] by Source in Poland in the Period 1973 – 2015.



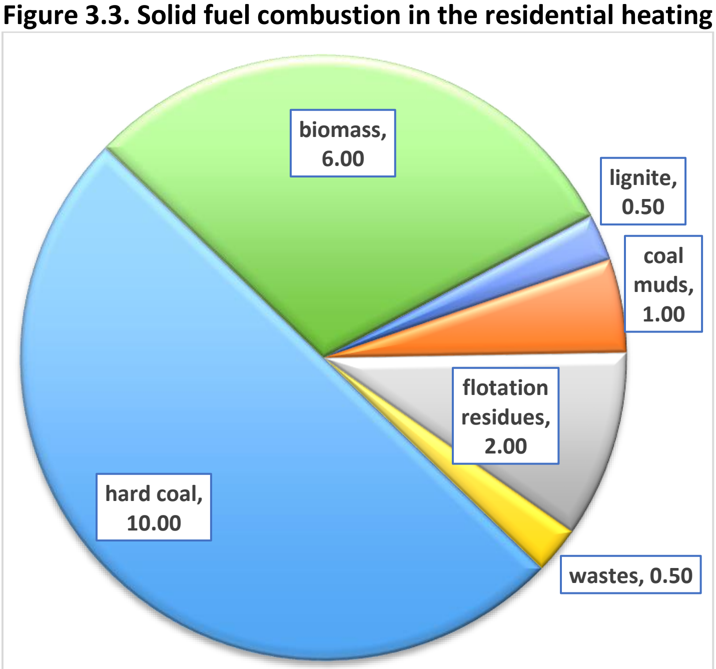
* Negligible.

Note: Coal includes coal-related gases (coke oven gas, blast furnace gas and other recovered gases).

Source: IEA, 2017.

Studies in Poland all point to residential heating as the most important source of ambient air pollution, especially particulate pollution, in Poland. It is estimated that each year the residential sector burns more than twenty million tons of solid of various types (Figure 3.3).

Figure 3.3. Solid fuel combustion in the residential heating sector (millions of tons)



Source: Stove Summit, 2017

The burning of polluting fuels in unregulated boilers in homes, along with burning of waste products in household boilers and stoves is responsible for the exceedances of air quality standards for $PM_{2.5}$, PM_{10}, and B[a]P pollution in the country. These air quality impacts are due to four major factors (CSO 2017b):

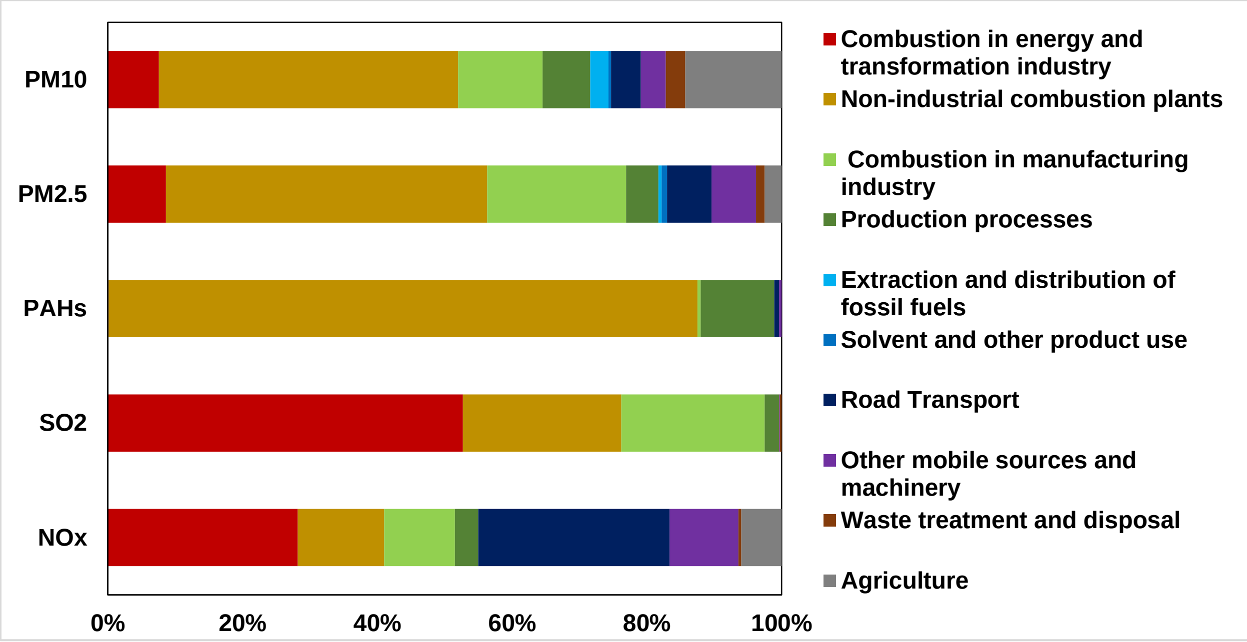
- poor quality of fuels
- ineffective combustion, because it is carried out in old boilers and stoves, with average ages of 10 years and over 24 years, respectively
- pollutants generated during combustion are not captured by any air pollution control devices
- pollutants are emitted to the air through low height stacks, therefore they concentrate where they originate, i.e. typically in densely populated built-in housing areas.

Overview of Emission Sources

Different macro-economic sectors of the Polish economy contribute to emissions of the various air pollutants. The only available nation-wide emission inventory is the official inventory prepared by the National Centre for Emissions Management (KOBiZE), which is under the Ministry of the Environment. Figure 3.4 illustrates those contributions based on a methodology called Selected Nomenclature for sources of Air Pollution (SNAP).[20] The main source of $PM_{2.5}$ and PM_{10} emissions is "non-industrial combustions plants" which refers to the residential sector (KOBIZE 2018). This sector is also the most important source of Benzo[a]Pyrene. Combustion in manufacturing industry is the next largest source of $PM_{2.5}$ emissions after residential, followed by the energy and transformation sector, road transport and others. Agriculture is the next largest contributor of PM_{10} emissions after the residential sector, followed by manufacturing industry. Energy combustion remains a very important source of SO_2, NO_x, and to a lesser extent PM.

20 https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep

Figure 3.4. Contributions of different macro-sectors to emissions of the main air pollutants in Poland in 2015.

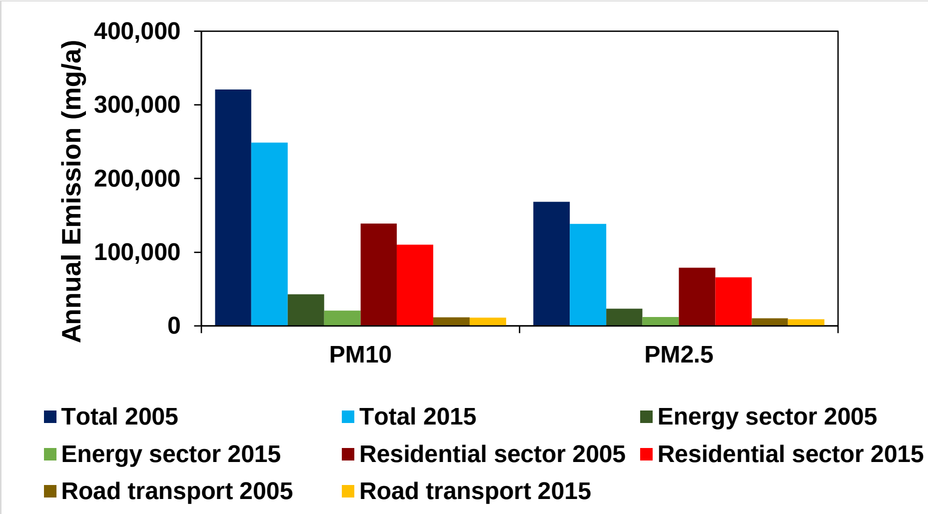


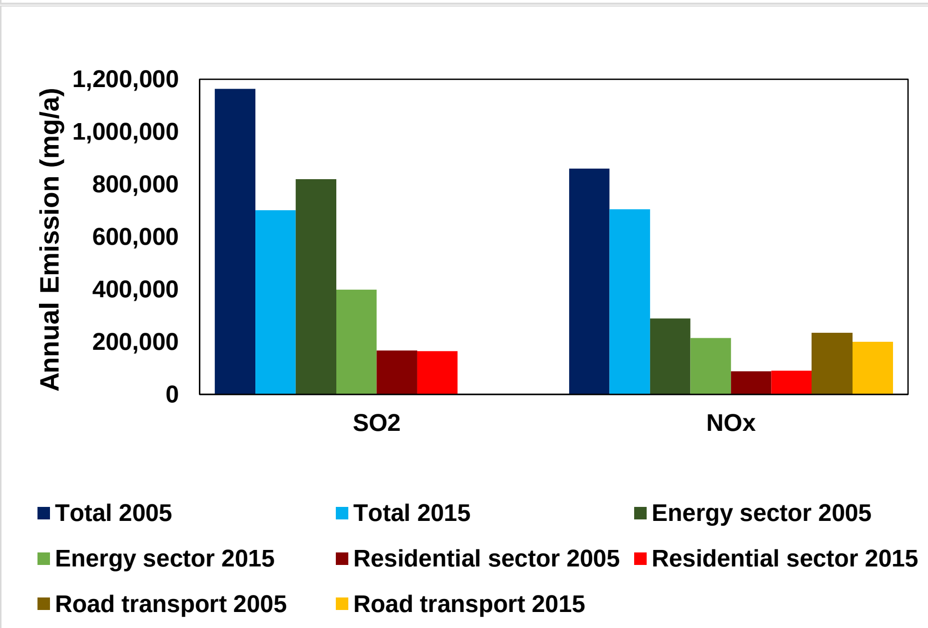
Source: Authors based on data from KOBIZE, 2018

A further look at the residential sector shows that in 2005 its contribution was approximately 47% of total $PM_{2.5}$ emissions and in 2015 it was approximately 48%--virtually unchanged as a percent of the total, although during this time total $PM_{2.5}$ emissions fell significantly. The situation is similar for PM_{10} emissions, the residential sector was responsible for about 43% of emissions in 2005 and for 44% in 2015. In contrast, the energy sector is the most significant source of SO_2 and NO_x pollution, though concentrations of these pollutants are no longer significant (Figure 3.4 and Figure 3.5).

As noted above, agriculture is also an important source of PM_{10} emissions. Although open burning of agricultural residues is banned under EU regulation No 1306/2013, a number of Member States report substantial emissions from this category, and this share is expected to increase in the future without further policy interventions. The application of nitrogen-based fertilizer in agriculture results in ammonia (NH_3) emissions, which can combine in the atmosphere with substances such as SO_2 and NO_x, themselves emitted by industry and vehicular traffic, to form secondary particulate matter. It is estimated that application of fertilizer in agriculture accounts for approximately 20% of total NH_3 emissions in the EU-28, and an additional 75% of the total is caused by manure management from livestock farming (Amann et al. 2017).

Figure 3.5. Emissions of PM_{10}, $PM_{2.5}$ (top panel), SO_2 and NOx (bottom panel) [Mg/a] as total annual emissions (blue) and emissions from energy (green), residential (red) and road transport (yellow) macro-sectors for 2005 (shadow bars) and 2015 (light bars).)





Source: Authors based on data from KOBIZE, 2018

Poland's car fleet is the oldest and sixth largest fleet in the European Union with 24.3 million cars, after Germany, Italy, France, the UK and Spain. The Polish truck and bus fleets are the largest in the EU, comprising one sixth and one seventh of the total EU's truck and bus fleet, respectively. The growth rate of the fleet is quite high. In just 5 years (2011 – 2015) the total number of vehicles in Poland increased by 15%. Additionally, car owners may remove the diesel particulate filters from diesel cars to reduce their maintenance costs. Diesel cars without these filters emit more harmful substances, and at best these cars can meet only Euro 3 emission standards. However, the contribution of transport to polluting emissions and air quality need to be better understood and quantified, especially the role of imported used vehicles.

Recently a new source of air pollution has arisen in Poland. As many as about 70 landfill fires have been noted in the country since the beginning of 2018 in which thousands of tons of wastes, including tires, chemicals, recycled cars, hazardous wastes as well as wastes collected in sorting plants are being burned. The increased number of incidences of waste burning coincides with China's ban on foreign waste imports, leaving Poland without a place to export its wastes.

Future Emissions and their Sources

Poland has taken several regulatory steps to tackle air pollution, including adoption of EU regulations and development of national legislation. As a member of the European Union, Poland is obliged to comply with a suite of European air quality directives. This section analyses the impact of different air quality management regulatory scenarios to understand the future emissions of $PM_{2.5}$ and its precursors.

GAINS (Greenhouse Gas-Air Pollution Interactions and Synergies) methodology

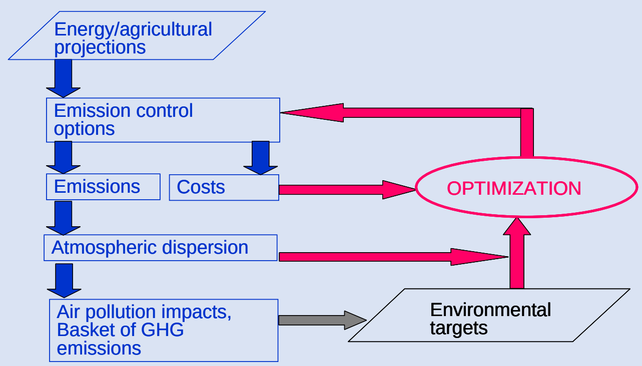
The GAINS model, developed at the International Institute for Applied Systems Analysis, can be used to simulate the impacts of proposed policies designed to influence future drivers emissions (e.g., energy consumption, transport demand, agricultural activities) (Amann et al. 2018). As with all models, these projections represent idealized versions of the effects of the policies and interventions that are being studied. The actual results will depend strongly on how these regulations and policies are implemented. A more detailed description of the GAINS model is presented in Box 3.1.

Box 3.1. The GAINS model

The GAINS model explores cost-effective multi-pollutant emission control strategies to meet environmental objectives for air quality and greenhouse gas emissions. GAINS, developed by the International Institute for Applied Systems Analysis (IIASA) in Laxenburg (Austria), brings together data on economic development, 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. GAINS addresses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions. GAINS describes the interrelations between these multiple effects and the pollutants (SO_2, NO_x, PM, NMVOC, NH_3, CO_2, CH_4, N_2O, F-gases) that contribute to these effects at the regional scale.

GAINS assesses, for each of the source regions considered in the model, more than 1000 measures to control emissions to the atmosphere. It computes the atmospheric dispersion of pollutants and analyses 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.

Figure B3.1.1 The flow of information in the cost-effectiveness analysis of the GAINS model



Source: Amann et al. 2018

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. The GAINS model draws on international and national statistical data on energy use, which provide rather robust information for fossil fuel use and key economic sectors (Amann et al. 2018). Currently, however, emission inventories remain an important and uncertain element of Poland’s air quality management framework.

This uncertainty is particularly evident in the residential sector, which is the leading source of particulate matter emissions in Poland. For GAINS implementation, it is known that data for the residential sector, and especially for household heating devices, is often of poor quality or suffering from large uncertainties. This includes information about the use of non-commercial biomass (wood logs), low quality coal (including coal waste, i.e., coal muds or flotation residues[21]), and municipal waste, for which the real amounts are often unknown and/or not well reflected in Poland's national statistics. In addition, official statistical data often do not include information about the structure of fuel use in the residential sector, i.e., allocated to heating stoves, manual boilers, automatic boilers, pellet stoves. Therefore, this study conducted a review and update of data availability for solid fuel use (coal and biomass) for household heating, including information about combustion technologies and their likely future evolution.

Calculation of emissions PM and PM precursors

Updated fuel use data by combustion technology were then used in the GAINS model application to calculate emissions of $PM_{2.5.}$, particulate black carbon (BC), and particulate matter precursor emissions (SO_2, NO_x, NMVOC, NH_3). The resulting emission estimates have been compared for 2005 (the base year of the NEC Directive[22]) and for 2015 (the latest year with historical statistics in the GAINS model) with available national and regional inventories (Amann et al. 2018, KOBIZE 2018). Emission scenarios were then used to evaluate the impacts of existing and planned national and international legislation.

Emission control costs

The GAINS model estimates costs that are associated with the implementation of the emission controls specified in a scenario. It uses the annual cost method and applies a social discount rate of 4% per year. All costs are in Euro 2005.[23] Cost calculations distinguish investment and operating costs of dedicated pollution control equipment, based on Polish experience, but do not include the costs for the improvement of energy supply infrastructures, such as distribution networks for natural gas and district heating (Amann et al. 2018). Costs for mitigation of emissions from residential coal combustion are based on Polish data provided in KOBiZE, 2016), assuming that by 2030 only coal of high quality will be used in the residential sector, at a price of 700 PLN/t, which translates into 5.8 Euro 2005/GJ.[24]

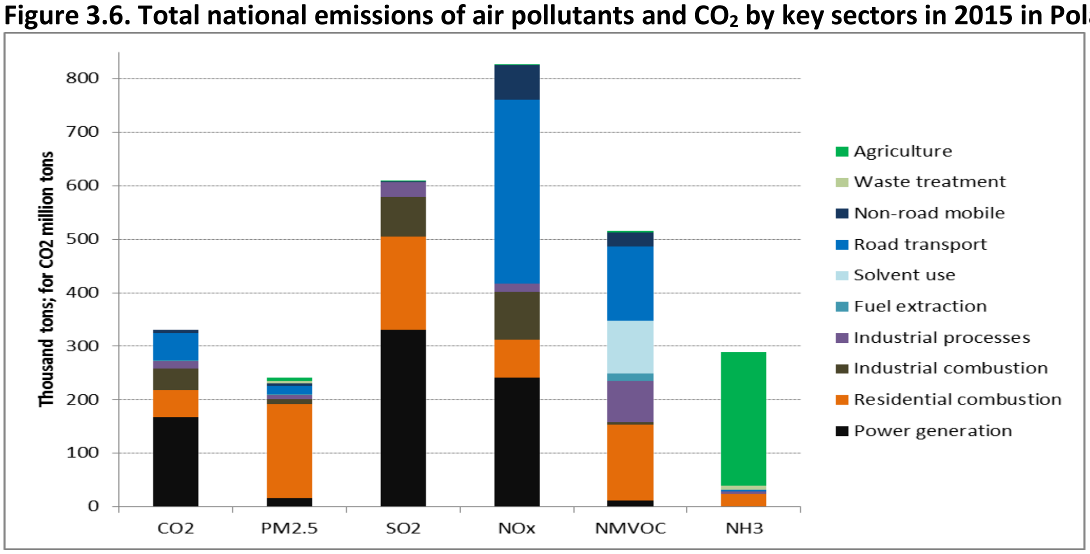
Results of GAINS Modelling

21 Both types of coal wastes are used mainly in Upper Silesia and małopolskie voivodeship
22 Directive 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants
23 For measures that influence more than one pollutant at the same time, GAINS attributes their total costs to the main pollutant. In particular, if a measure reduces (inter alia) NOx emissions (like for instance Euro measures on transport sources), all costs of those measures are reported under NOx. Second priority is given to PM, i.e., if a measure reduces PM and other pollutants (but not NOx), all costs are reported under PM. This is why no costs are reported in the PM cost table for transport.
24 Costs of boilers (in current PLN) are as follows: three thousand for no class, seven thousand for class 3 and ten thousand for class 5. Class five boilers meet the Eco-design standards.

Emissions Estimates

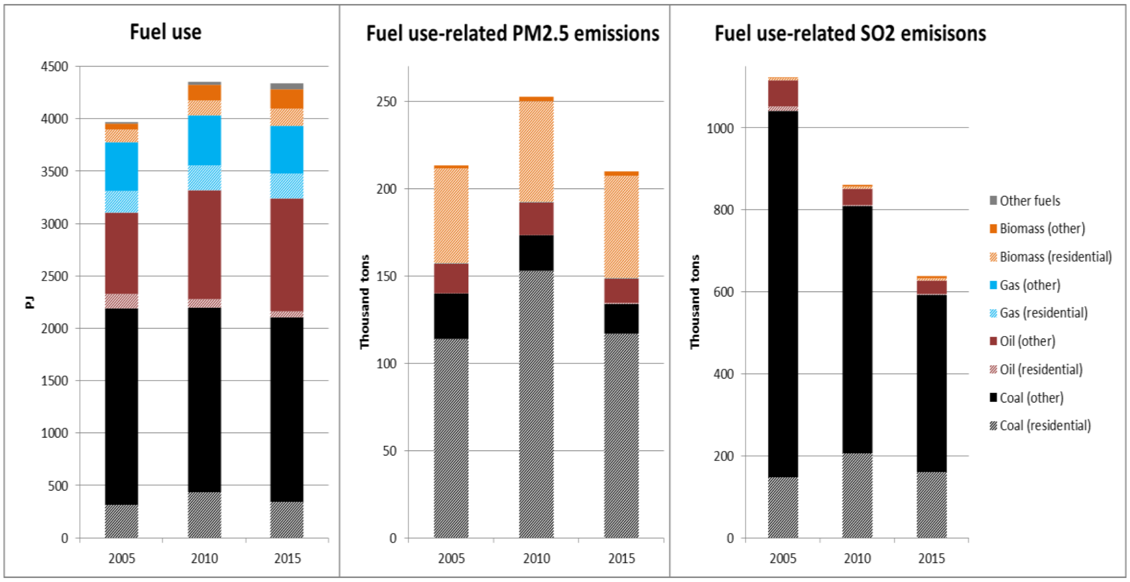
Figure 3.6 illustrates the total national emissions of various air pollutants and CO_2 in 2015 and the contributing sectors as estimated by the GAINS model. In 2015, about half of Poland's CO_2 emissions originated from the power sector, with the rest split about evenly between the residential, industrial, and transport sectors (Figure 3.6). About 80% of $PM_{2.5}$ total emissions originate from the combustion of solid fuels in the residential sector due to the dominance of small combustion devices without emission controls. Coal consumption contributed an important share of air pollutants and CO_2 emissions (Figure 3.7). Although only 20% of all coal is used for residential combustion (Figure 3.7, left), this generates 80% of all coal-related $PM_{2.5}$ emissions (Figure 3.7, middle). Similarly, all $PM_{2.5}$ from biomass combustion emerges from the residential sector although only half of all biomass is used there; and the remaining biomass is used in power sector and industry. Power plants and their coal use are key for emissions of SO_2 and contribute a significant share of NO_x, while the transport sector dominates NO_x and represents a large share of NMVOC (non-methane volatile organic compounds) emissions. The growth in imports of old cars, which pollute much more than new cars can be seen in Figure 3.8.

Figure 3.6. Total national emissions of air pollutants and CO_2 by key sectors in 2015 in Poland



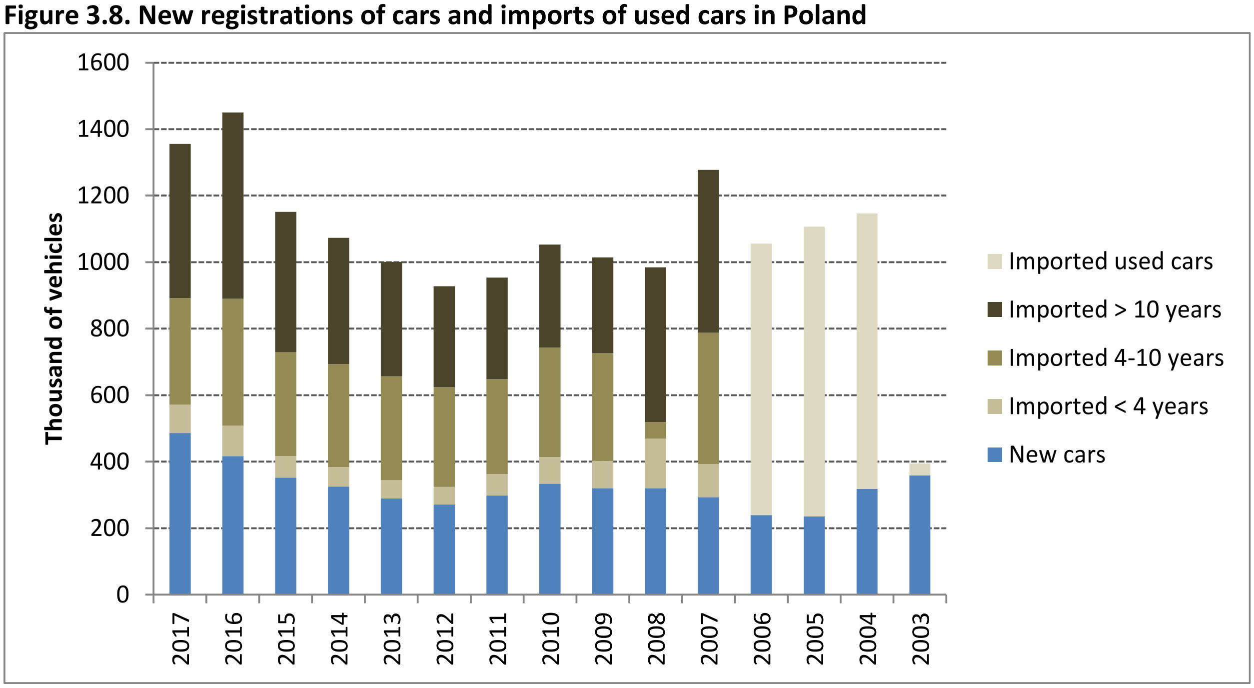
Source: GAINS model

Figure 3.7. Fuel use and related emissions of $PM_{2.5}$ and SO_2 in Poland



Source: GAINS model

Figure 3.8. New registrations of cars and imports of used cars in Poland



Sources: ACEA and Polish Ministry of Finance

Compared to the GAINS estimates, some studies suggest higher relative shares of PM emissions from transportation in Poland (Dzikuć et al., 2017), primarily due to much lower estimates of PM emissions from residential sources. The GAINS emission estimates for transport sector agree quite well with the recent Polish national inventory. At the same time, however, all estimates of transportation emissions in Poland are burdened with important uncertainties associated with imported second-hand vehicles (Figure 3.8). According to the European Automobile Manufacture Association (ACEA) and data from the Polish Ministry of Finance, imported used cars that are older than 10 years account for about one third of all new registrations. These vehicles have been produced before 2009, i.e., before diesel particulate filters were required by European law. While these circumstances are considered in the GAINS estimates, their quantification remains uncertain due to limited data availability, e.g., on the actual mileage of these vehicles and their environmental performance.

Fuel Use, Stoves and Boilers in the Residential Sector

About half of the Polish energy demand is met by coal, and over 20% of that coal is used in the residential sector, mainly hard coal. However, it is likely that household coal use might be even higher since fuel use statistics for the residential sector in Poland suffer from significant uncertainties with respect to coal use (Stala-Szugaj 2017), and underestimate fuelwood consumption (ECE 2018). For example, national and regional estimates of coal consumption do not include lignite and coal wastes. Several independent estimates suggest that about 0.5-1 million tons of lignite, about 3 million tons of coal muds and flotation residues, and 0.5-1 million tons of waste is used in residential stoves and boilers (e.g., KOBIZE, 2016). In addition, significant amounts of biomass use are suggested for the residential sector; estimates range between 6-8 million tons (Stove Summit, 2017) and about 14-15 million tons (ECE, 2018). A summary of fuel consumption estimates and comparison to the GAINS model assumptions is provided in Annex C.

Nearly half of the residential heat demand is supplied by individual heating systems using solid fuels, less than 9% by single gas boilers, and the rest mainly by district heating. This structure causes high emissions of particulate matter from the residential sector, especially since most of the solid fuel boilers and stoves are rather old and polluting. The number of households and boilers/stoves is shown in Table 3.1. Emissions in the residential sector also depend on the type and age of combustion device, due to large differences in their emission factors. Annex C presents existing information on the structure of combustion installations by fuel type in Poland as well as updates of the same produced by this study.

Table 3.1. Structure of installations in 2011 and fuel use in the residential sector in 2016 in selected voivodeships and cities in Poland.

	Total number of households [pcs]	Number of boilers - coal [pcs]	Number of stoves - coal [pcs]	Total number of coal boilers & stoves [pcs]	Hard coal use [Mt]	Natural gas use [TJ]	Light heating oil use [Mg]
dolnośląskie	1 019 754	221 851	174 261	396 112	0.829	12 851	5 000
Wrocław	254 843	9 901	23 825	33 726	-	-	-
małopolskie	995 329	277 691	145 679	423 370	0.943	15 111	4 000
Cracow	308 461	9 182	14 412	23 594	-	-	-
mazowieckie	1 820 197	311 109	186 440	497 549	1.421	31 276	12 000
Warsaw	738 120	6 594	8 990	15 584	-	-	-
śląskie	1 609 361	376 853	256 568	633 421	1.448	15 813	7 000
Katowice	129 221	7 608	20 578	28 186	-	-	-
POLAND	**12 525 412**	**2 999 807**	**1 926 900**	**4 926 707**	**10.350**	**145 148**	**70 000**

Source: CSO, 2011, 2017a

The GAINS database on default emission factors for particulate matter, specifically $PM_{2.5}$, incorporates information from a vast number of measurements for various types of installations and fuels. In general, results of local measurement campaigns compare well with the GAINS emission factors for solid fuel stoves and boilers currently in use. However, the emission factors that are currently used in the national emission inventory (KOBIZE, 2018) based upon the recommendations of the Polish Ministry of Environment (MoE, 2003) appear low, leading to comparably low estimates of $PM_{2.5}$ emissions from the residential combustion sector. Additionally, there are significant uncertainties in emission factors for coal residues (Amann et al. 2018). For example, the measured emission factors from installations using floatation residues (IChPW, 2017) were found to be similar to those of manual coal boilers, which contrasts with findings presented in another study where a significant impact on PM2.5 concentrations (lower concentrations) was measured after floatation residues were replaced with good quality coal (KOBIZE, 2016).

Emission inventories

Emissions from the residential sector are strongly influenced by illegal waste combustion and the use of coal waste[25] (KOBIZE 2016, Stala-Szugaj 2017); a practice which is still not prohibited at the national level. The amount of household waste and coal waste combusted in the country are not reported, and so are difficult to estimate.

The national emission inventory prepared by KOBIZE (2018) and submitted by Poland to the Convention on Long Range Transboundary Air Pollution (LRTAP) in 2017 and 2018[26] has been compared with the GAINS estimates, which have been carried out for all European countries in

25 Such as coal muds, flotation residues etc.

26 The national reporting is updated regularly (including revision of estimates for historical years) due to, inter alia, updates of methods, updated activity data, changes to reporting formats

a coherent way. The comparison includes the five pollutants covered by the NEC Directive 2016/2284/EU, i.e., NO_X, NMVOC, SO_2, NH_3 and $PM_{2.5}$. A comparison shows rather small differences from the GAINS estimates at the national level (typically below 10%; Table 3.2). However, figures for $PM_{2.5}$ and NMVOC differ, for $PM_{2.5}$ by a factor of two, mainly related to discrepancies in the residential sector.

Table 3.2. Polish emissions Reported in 2017 and 2018 Compared to GAINS Estimates. The differences are shown as percentage of GAINS to submission in 2017 and 2018, respectively. All values in thousands of tons

	NO_x		NMVOC		SO_2		NH_3		PM2.5	
	2005	2015	2005	2015	2005	2015	2005	2015	2005	2015
National submission (2017)	813	674	543	531	1164	690	299	267	159	125
National submission (2018)	824	665	606	591	1164	702	300	267	169	138
GAINS	784	702	583	435	1174	701	314	289	252	249
Difference to GAINS of 2017/2018 [%]	-4/-5	4/6	7/-4	-18/-26	1/1	2/0	5/5	8/8	59/49	99/80
Change in national reporting (2018/2017)	1%	-1%	12%	11%	0%	2%	0%	0%	6%	10%

Source: GAINS Model

At the sectoral level, both assessments appear consistent, with the exception of the estimates for the residential combustion sector and of NMVOC emissions. The GAINS estimates of $PM_{2.5}$ from residential combustion are higher by a factor of 2.7, mainly as a result of differences in emission factors and activity statistics for solid fuel stoves and boilers.

Development of Emission scenarios using GAINS Methodology

This study examined six emission scenarios extended to 2030 using the GAINS model. The baseline activity projections are referred to as the PRIMES[27] 2016 REFERENCE scenario, which was developed for the European Commission. The scenarios were used to illustrate the consequences of different assumptions about policies and measures and are summarized in Table 3.3:

1. Current legislation without the Eco-design Directive – baseline scenario
2. Current legislation with the Eco-design Directive
3. Current legislation with the national and regional air quality plans (NRAQP)

[27] Price-Induced Market Equilibrium System (PRIMES) is an EU system model, which simulates energy consumption and the energy supply system.

4. National Emission Ceilings Directive (NECD) with the Eco-design Directive
5. National Emission Ceilings Directive (NECD) with the NRAQP
6. Maximum Technical Mitigation Potential (MTFR) scenarios

Current legislation without the Eco-design Directive. This baseline scenario for 2030 considers legislation in place by 2017, with the exception of the Eco-design Directive and the emissions targets specified in the NEC Directive; the latter two elements are addressed in specific policy scenarios to single out their impacts on air emissions and $PM_{2.5}$ concentrations and also compare with the alternative policies including regional air quality plans and maximum mitigation case.

Current legislation with the Eco-design Directive is the policy scenario that explores the impacts of a timely and effective EU-wide implementation of the recently adopted EU Eco-design Directive, which specifies energy efficiency standards as well as emission limit values (ELVs) for new small combustion devices using solid fuels. For Poland, the Eco-design Directive implies also abandoning the use of waste coal and an effective ban of waste combustion in household installations. This scenario also assumes implementation of all legislation in place by 2017, as in the baseline scenario.

Current legislation with the national and regional air quality plans is the policy scenario that illustrates the impact of recently adopted and planned national and regional legislation. It includes all legislation as defined in the baseline scenario above (note, it excludes Eco-design), and adds requirements that stem from the National Air Quality Plan (MoE, 2015), Clean Air Programme, standards for solid fuel boilers (Journal of Laws (JoL) 2017, item 1690), national fuel quality standards, and regional Anti-Smog Requirements, e.g., earlier implementation of Class 5 boilers and scrapping of existing boilers. This is a very ambitious scenario with respect to the defined time schedule, and especially on the enforcement of early retirement of existing installations that are non-compliant with Class 5 or Eco-design requirements. For this assessment full compliance is assumed in order to illustrate the potential benefits of ambitious and immediate action targeting solid fuel heating installations in the residential sector.

National Emission Ceilings Directive (NECD) with the Eco-design Directive This policy scenario for 2030 achieves the emission reduction requirements of the National Emission Ceilings Directive (NECD, 2016/2284/EU)[28] and includes compliance with the Eco-design Directive in Poland. This scenario assumes a cost-effective mix of measures to achieve the EU-wide NECD goals

National Emission Ceilings (NECD) with the NRAQP is the scenario for 2030 that achieves the emission reduction requirements of the National Emission Ceilings Directive (NECD,

28 More discussion of the EU wide analysis for the NECD has been documented in the recent studies for the European Union (http://ec.europa.eu/environment/air/clean_air/outlook.htm)

2016/2284/EU). Instead of the Eco-design Directive, it assumes implementation of the national and regional policies as in the NRAQP scenario. This is an optimized scenario that assumes EU-wide compliance with the NECD goals.

The Maximum Technical Mitigation Potential (MTFR). This group of scenarios explore for 2030 in Poland[29] (a) the residential sector, (b) transport, (c) industry, and (d) all sources combined, including mitigation opportunities in agriculture. It illustrates the extent to which emissions could be further reduced through full application of all available technical measures (often referred to as BAT – Best Available Technology), beyond what is required by current legislation and the NRAQP requirements.[30] The MTFR scenario assumes EU-wide compliance with the NECD goals.

Table 3.3. Summary of the Scenario Definitions;

Scenario	Included legislation/policy				
	CLE	Eco-design	NRAQP	NECD goals	MTFR
1. Current legislation (CLE) - Baseline	●				
2. Eco-design Directive	●	●			
3. National and regional plans (NRAQP)	●		●		
4. NECD compliance, incl. Eco-design	●	●		●	
5. NECD compliance, incl. NARQP	●	●	●	●	
6. Maximum technical mitigation (MTFR)	●	●	●	●	●

'●' indicates included legislation/policy. Source: Amann et al. 2018

Results – Future Development of $PM_{2.5}$ Emissions

Figure 3.9 illustrates the evolution of $PM_{2.5}$ emissions until 2030 in the different scenarios as computed by the GAINS model. The assumptions of the current baseline scenario lead to a decline of the emissions of key components of particulate matter (primary $PM_{2.5}$, SO2, nitrogen oxides) by 30-40% until 2030. Main contributory factors are declining coal use in the residential sector and assumed full compliance with the European Union legislation for large combustion plants and industry. In contrast, ammonia emissions will most likely increase making agriculture, the key source of ammonia emissions, an even more important contributor to the formation of $PM_{2.5}$ in ambient air (see Figure C.4 in Annex C).

The introduction of the Eco-design Directive could bring significant reductions of primary PM, black carbon and NMVOC emissions, leading to a further decline in $PM_{2.5}$ concentrations in

29 For the rest of the EU the scenario assumes compliance with the current legislation including NECD targets.

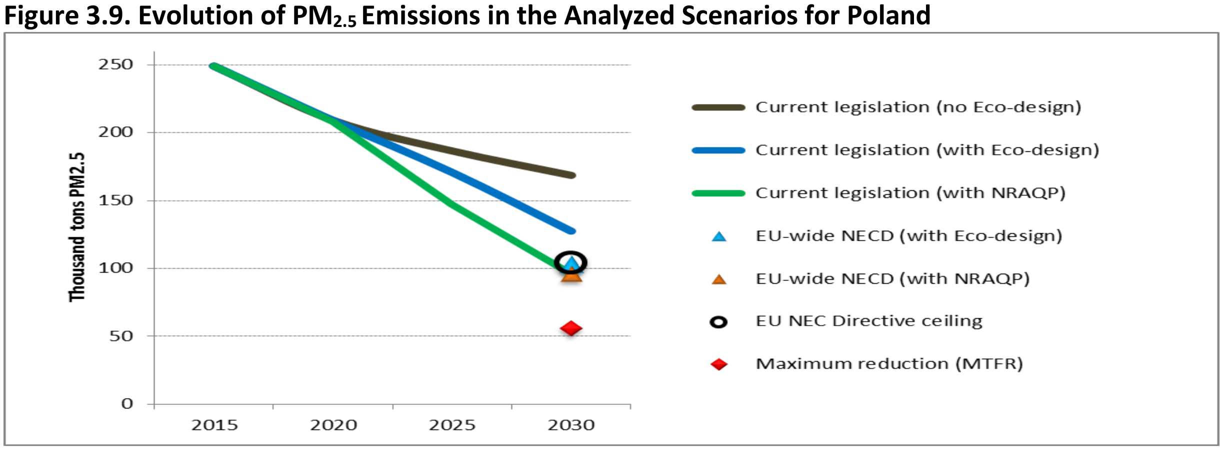
30 These scenarios do not consider premature scrapping of existing capital stock, i.e., new and cleaner devices are only allowed to enter the market when old equipment is retired naturally. Furthermore, they ignore any potential changes in the energy structure and do not imply behavioural changes of consumers.

Poland. However, the Eco-design Directive alone would not necessarily be sufficient to comply with the Polish emission reduction requirements of the NEC Directive for $PM_{2.5}$ (Figure 3.7) and therefore further reductions of industrial emissions are necessary. More stringent legislation in the residential sector, as suggested by the anti-smog regulations (NRAQP), would bring emissions of particulate matter to the levels agreed under NEC (Figure 3.6) and deliver further improvements in ambient $PM_{2.5}$ levels.

Since current legislation (as defined in the baseline scenario) brings necessary reductions of SO_2, NO_x, and NMVOC, the introduction of Eco-Design or NRAQP measures contributes to slight overachievement of NEC targets for these pollutants. For ammonia, however, neither Eco-design nor NRAQP bring additional reductions and therefore, agricultural emissions need to be reduced significantly (by about 25% relative to baseline for 2030) in order to comply with the NEC target for ammonia. Results for pollutants other than PM2.5 are presented by sector in Figure C.1 through Figure C.5.

The maximum technically feasible reduction (MTFR or BAT) scenario offers further mitigation for $PM_{2.5}$ (Figure 3.9) in most of the sectors, including power plants, industry, residential combustion, and agriculture. Only very limited reduction is estimated for transport (primarily non-road machinery) owing to very strict legislation already in place requiring low sulphur diesel fuels and Euro VI/6 standards on diesel as well as gasoline vehicles. However, this scenario results in very high costs, e.g., nearly doubling costs for PM control compared to the NECD compliant cases.

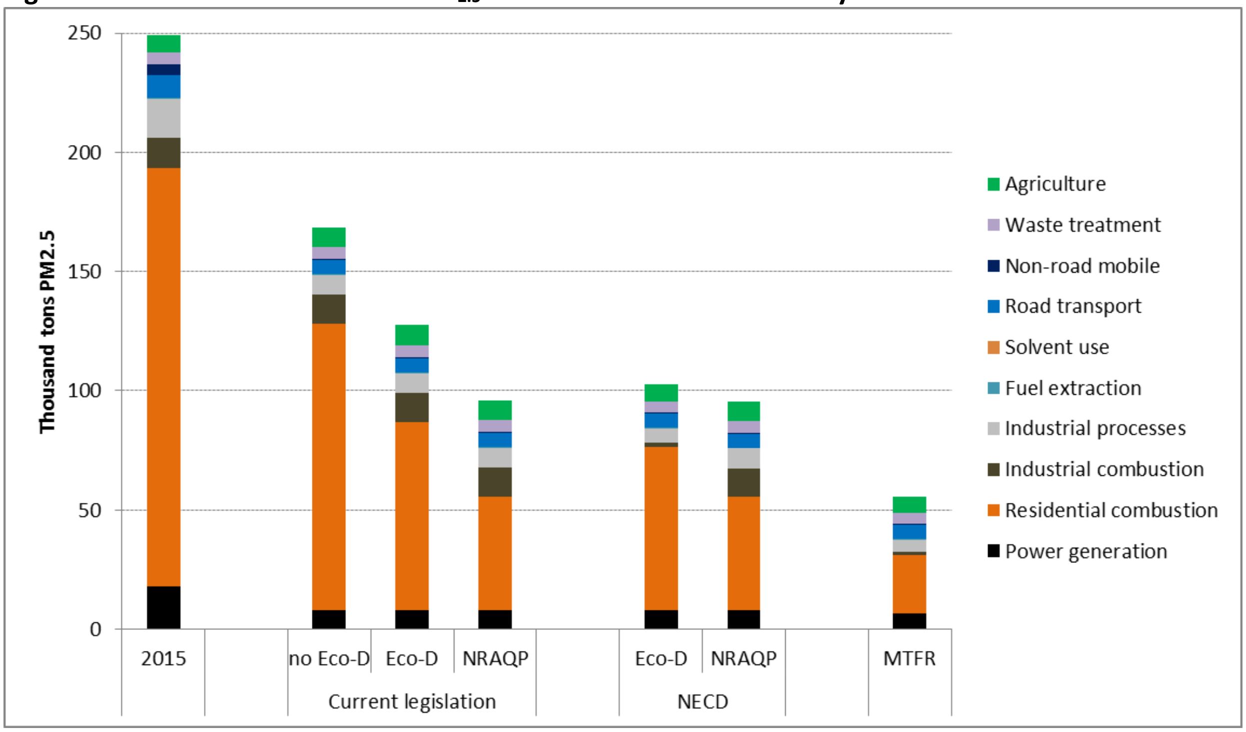
Figure 3.9. Evolution of $PM_{2.5}$ Emissions in the Analyzed Scenarios for Poland



Source: GAINS Model

Under these same scenarios up to 2030, the sector specific reductions in $PM_{2.5}$ emissions can be seen in Figure 3.10. Compared to 2015, the large reductions in these emissions are always from residential combustion. Both Eco-Directive scenarios, under either existing legislation or under the National Emission Ceiling Directive, lead to significant reductions of $PM_{2.5}$ emissions. Agricultural emissions are relatively unchanged under any of the scenarios, however.

Figure 3.10. Sectoral emissions of $PM_{2.5}$ in Poland in 2015 and in analyzed scenarios for 2030



Source: GAINS model

Projected CO_2 Emissions **up to 2030**

Since significant amounts of coal are used in the Polish residential sector, this study also examined the potential for CO_2 mitigation from the sector. It is estimated that in 2015 the residential sector accounted for about 15% of total CO_2 emissions in Poland and by 2030 its share will decline to about 12% in the baseline scenario (Table 3.4). Residential coal combustion was responsible for about two-thirds, i.e., less than 10% of the national total in 2015 and since coal use is expected to decline by about 40% by 2030 its share will be about 6% in total.

Table 3.4. CO_2 emissions by key sectors (million tons)

	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	162.1	155.2	155.2	155.2	155.2	155.2	155.2
Residential combustion	50.2	38.0	37.4	35.9	37.4	35.9	35.9
Industrial combustion	36.4	32.6	32.6	32.6	32.6	32.6	32.6
Industrial processes	24.2	27.8	27.8	27.8	27.8	27.8	27.8
Road transport	50.3	54.3	54.3	54.3	54.4	54.4	54.4
Non-road mobile	5.8	5.5	5.5	5.5	5.5	5.5	5.5
Sum	**329.0**	**313.4**	**312.8**	**311.3**	**312.9**	**311.4**	**311.4**

Source: GAINS model

The new stoves and boilers introduced in the analysed mitigation scenarios have higher efficiency and will result in about 10% reduction of CO_2 emissions from coal combustion in this sector, but this translates to about 5% of total residential sector or less than 1% of the total national CO_2 emissions in 2030 (Amann et al. 2018). Consequently, estimates of CO_2 mitigation potential from coal combustion in Polish households are quite small, when only changes to more efficient stoves and boilers are pursued. Higher reductions could more likely be achieved with further expansion of gas and district heating.

Projected concentrations of Ambient $PM_{2.5}$ up to 2030

GAINS calculations at a 7 × 7 km spatial resolution indicate that in 2015 the WHO guideline value for $PM_{2.5}$ of 10μg/m^3 was exceeded in most of Poland, and concentrations in southern Poland also violated EU Limit Value of 25μg/m^3 (Figure 3.11, top left).

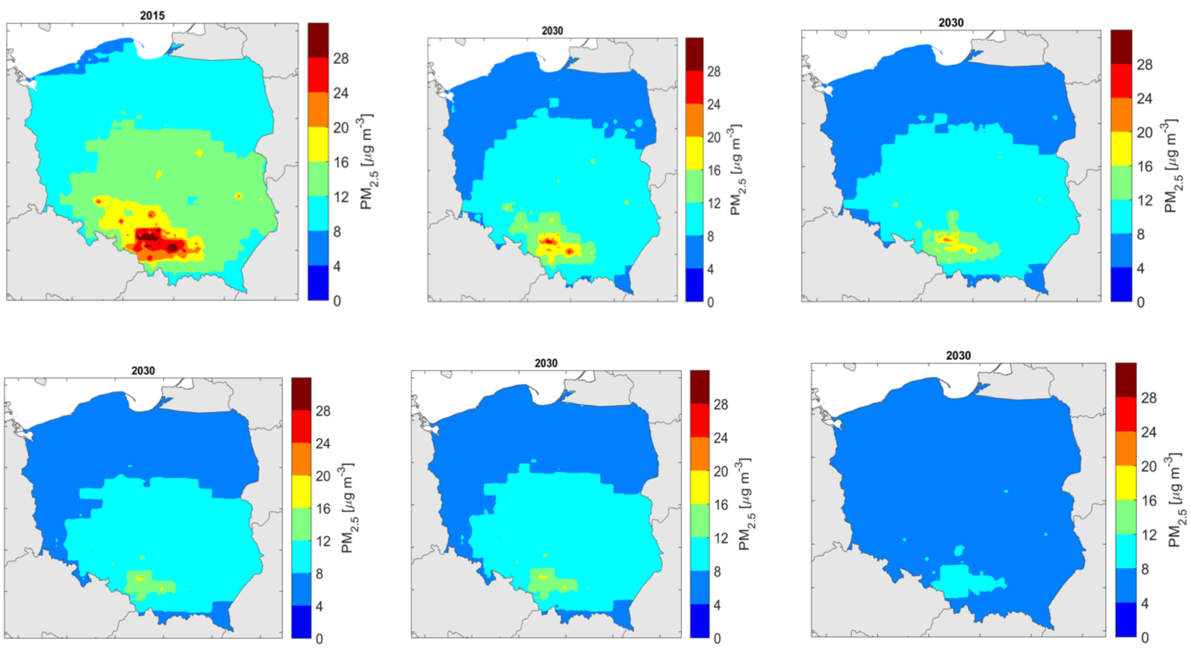
The improvements in ambient $PM_{2.5}$ concentrations under the various scenarios are shown in Figure 3.11. In the baseline case, energy policy and emission regulations lead to a strong decline in SO_2, NOx, $PM_{2.5}$ and NMVOC emissions, while NH_3 continues to increase. Consequently, already in the baseline scenario, annual mean $PM_{2.5}$ concentrations in ambient air will decline in most of Poland (Figure 3.11, top middle), although southern Poland will continue to experience much higher $PM_{2.5}$ levels, above the WHO guideline level. In the Katowice conurbation, only small improvements can be expected.

The Eco-design (Figure 3.11, top right) and the national plans (NRAQP case, Figure 3.11, bottom left) scenarios bring benefits especially in the south of Poland, which will significantly enlarge the areas complying with the EU limit value legislation and the WHO guideline, respectively.

The scenario which combines strong action in Poland to achieve the ambitious goals for the national and regional air pollution plans (NRAQP) with EU-wide compliance with the NEC Directive achieves further improvements and only very limited areas in southern Poland would remain in violation of the WHO guideline (Figure 3.11, middle bottom).

Finally, full exploitation of the technical emission reduction potential in Poland (MTFR), combined with the NEC Directive in the other EU Member States, would reach the WHO guideline value in almost all of Poland, despite the continued use of solid fuels in the residential sector (Figure 3.11, bottom right).

Figure 3.11. $PM_{2.5}$ concentrations estimated for 2015 (top left) and for 2030: Current legislation (excluding Eco-design) (top middle), including Eco-design (top right), including NRAQP (bottom left), including EU-wide NECD and NRAQP in Poland (bottom middle), and MTFR case (bottom right)[31]



Source: GAINS model

Emission control costs

The projected cost of $PM_{2.5}$ emissions reduction from the residential sector are analyzed and compared to similar costs for other key sectors (Table 3.5). The GAINS model estimates costs

31 Note that the map for the scenario, where EU-wide application of NECD and Eco-design is assumed, is not shown as the concentrations resemble the case with Eco-design only.

that are associated with the implementation of the emission controls specified in a scenario. It uses the annual cost method and applies a social discount rate of 4%/year. All costs are in Euro 2005[32].

Table 3.5. PM emission control costs by key sectors and total costs including measures for all other pollutants, million Euro per year

	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	576	555	555	555	555	555	559
Residential combustion	69	126	284	353	284	353	772
Industrial combustion	31	34	34	34	34	34	45
Industrial processes	215	263	263	263	263	263	358
Fuel extraction	43	35	35	35	35	35	35
Agriculture	9	9	9	9	9	9	294
Sum PM sources	**943**	**1,022**	**1,179**	**1,248**	**1,179**	**1,248**	**2,061**
Sum all pollutants	**2,620**	**9,044**	**9,199**	**9,257**	**9,187**	**9,245**	**11,787**

Costs for mitigation of $PM_{2.5}$ emissions from residential coal combustion are based on Polish data provided in a study by KOBiZE (KOBiZE, 2016), assuming that by 2030 only coal of high quality will be used in the residential sector, at a price of 700 PLN/t, which translates to 5.8 Euro 2005/GJ[33].

Assuming natural replacement of boilers at the end of their technical lifetime, i.e., without the requirements of the Eco-design Directive or the Polish NRAQP, emission control costs in the baseline case are estimated at 126 million Euro/year. For the Eco-design scenario, costs increase to 284 million Euro/year or by 130 %. Costs for the NRAQP scenario are 353 million Euro/year i.e., are nearly thrice the baseline (current legislation) costs. The emission reduction requirements of the NEC Directive can be met without further measures beyond what the NRAQP requirements. Achievement of the maximum reductions (MTFR) would more than double the costs of the NRAQP.

PM emission control costs increase over time, which is a result of stricter legislation not only for the residential sector but also in other sectors, where meeting the air pollution standards

32 For measures that influence more than one pollutant at the same time, GAINS attributes their total costs to the main pollutant. In particular, if a measure reduces (inter alia) NOx emissions (like for instance Euro measures on transport sources), all costs of those measures are reported under NOx. Second priority is given to PM, i.e., if a measure reduces PM and other pollutants (but not NOx), all costs are reported under PM. This is why no costs are reported in the PM cost table for transport.

33 Costs of boilers (in current PLN) are as follows: PLN 3,000 for no class, PLN 7,000 for Class 3 and PLN 10,000 for Class 5. Class 5 boilers meet the Eco-design standards.

require installation of more efficient PM removal equipment. In 2015 costs of PM controls from all sectors accounted for 36% of the total cost of controlling emissions of all air pollutants. This share decreases to 11% in the current legislation baseline without Eco-design, 13% for the scenario with NRAQP, and 17% for the MTFR case. The reason for relatively low shares of PM costs, compared with the costs for all pollutants, are high and increasing costs of measures to meet emission limit values for mobile sources (road transport and non-road machinery – 68% of the total) and the costs of controlling SO_2 and NO_x emissions from the power sector (17% of the total in the NRAQP scenario).

Summary

This study provides an overview of key sources of particulate matter air pollution in Poland and identifies major opportunities for improving air quality in Poland. Solid fuels use for heating in households is the primary source of particulate matter pollution in most areas in Poland. These sources make a large contribution to ambient $PM_{2.5}$ concentrations, particularly those areas with high concentrations.

The current Polish emission inventory is likely to underestimate emissions from the household sector. There are a number of weaknesses in the emission inventories of the residential sector, including inconsistencies across the voivodeships even in the methods of performing the inventories. There are major uncertainties in real-life emissions, activity statistics, and very incomplete information about use of coal muds and flotation residuals. There are information gaps on the extent of use of non-commercial biomass use in stoves and boilers. Additionally, burning of waste in heating is highlighted as a potential problem in some areas.

Reducing emissions from solid fuel use in the domestic sector is critical for improvements in the ambient $PM_{2.5}$ concentrations in Poland. Verification of emissions inventories and monitoring results through computer modeling should be enhanced.

Full and timely implementation of current legislation, including Eco-design Directive, and its extension considering the nation-wide application of regional plans (e.g. anti-smog regulations) is essential for air quality improvements in Poland. Given the high ambition level of the regional plans, adequate financial and institutional support mechanisms will be required.

The air quality and health benefits of full implementation of the NRAQP will be substantial. It goes beyond the EU legislation by requiring replacement of existing installations, supported by financial mechanisms. The NRAQP is very ambitious with respect to the defined time schedule, and especially the enforcement of early retirement of existing installations that are non-compliant with Class 5 or Eco-design requirements.

Compliance with the reduction requirements of the NEC Directive and bringing air quality closer to the WHO $PM_{2.5}$ guideline value of 10 µg/m^3 requires, however, further measures beyond NRAQP, primarily for reducing ammonia emissions in the agricultural sector and emissions from industry. The need for further reductions of $PM_{2.5}$ emissions from industry depends on the success of the NRAQP implementation. An effective NRAQP implementation could minimize the necessity for additional measures in industry.

While the transport sector contributes also to $PM_{2.5}$ exposure, recent legislation on advanced Euro 6 standards is expected to deliver a significant drop of emissions from mobile sources; further technical measures are both very limited and costly.

Further mitigation, beyond current commitments and plans, is possible and can achieve sizable reductions of $PM_{2.5}$ emissions and health impacts. However, it would require strict legislation and enforcement of renewing the fuelwood and coal stoves.

New coal boilers and stoves, as in the NRAQP scenario, will reduce coal consumption and consequently CO_2 emissions from households. However, at a national level this effect will be rather small - about one percent of total national emissions. Higher reductions could be achieved through further expansion of gas and district heating systems.

Chapter 4. Benefit Cost Analysis of Emission Reduction Interventions

As has been described in earlier chapters, the most important air pollutant in Poland is $PM_{2.5}$ and the most important source of $PM_{2.5}$ pollution is residential heating. The only approaches to meeting the Limit Values and eventually meeting the WHO guideline is to significantly reduce emissions from this sector. Transport is also frequently an important source.

Given the scale of the particulate matter (PM) pollution problem, there should be an analytical approach to guide an effective and efficient path towards reducing the health risks associated with this PM air pollution. Typically, the allocation of public funds for environmental protection is prioritized through economic analysis. Various interventions can be compared for their relative effectiveness and cost-effectiveness. Interventions with higher net benefits are usually given priority. Benefit-cost (BC) ratios of the various interventions to clean up the most polluted areas in Poland can be used as one decision-making criterion. In this chapter the various EU legislative/policy directives, that are now part of Polish law, for reducing air pollution are used as scenarios up to 2030 and are analyzed by their benefit-cost ratios.

The following scenarios (originally defined in Chapter 3) are examined in this chapter:

1. Baseline (2015) or Current Legislation
2. National Emissions Ceiling Directive with Eco-design – NECD 1
3. National Emissions Ceiling Directive with the National and Regional Air Quality Plans (NRAQP) – NECD 2
4. Maximum Technically Feasible Reduction (MTFR, or BAT)

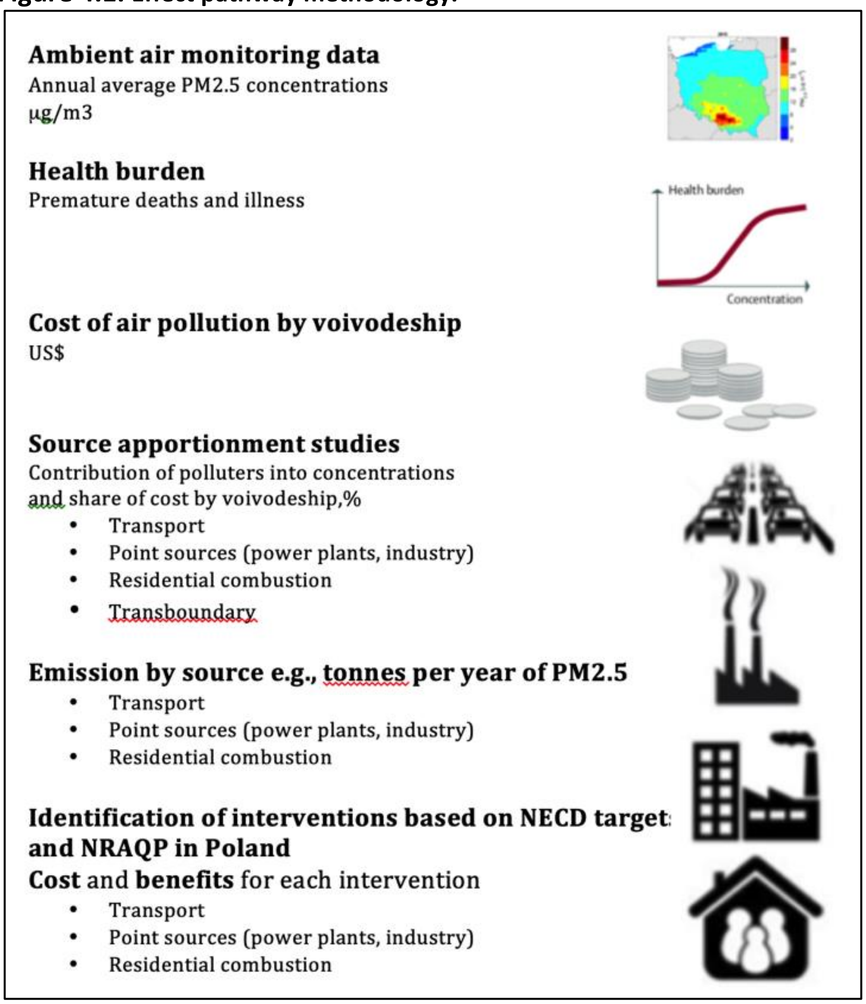
The benefit cost analyses were done for the most highly polluted areas in Poland i.e., in four voivodeships where the cost of health damage from ambient $PM_{2.5}$ pollution is highest. These were selected on the basis of $PM_{2.5}$ concentrations and exposures. and sets targets for pollution reduction based on EU directives and Air Quality Plans in Poland. Source apportionments in the most polluting voivodeships are used based on a recent study by the National Supreme Audit Office of Poland (SAO 2018). Costs are assigned to these scenarios of different emission control approaches of the EU directives and NRAQPs. The health benefits are quantified and compared to the implementation costs in each of the most polluted voivodeships.

Description of Analytical Approach

Effect Pathway Approach

The effect pathway approach (Markandya et al., 2007) is used to estimate benefits and costs of each intervention. The health effects of interventions to reduce air pollution can most easily be assessed by a bottom-up approach, in which emissions and hazards from each polluter are measured and tracked to the endpoints at which they cause harm to individuals. The effects are calculated for the specific polluter and location, i.e., for a given voivodeship with the most exceedances of $PM_{2.5}$ standards. The methodology is presented in Figure 4.1.

Figure 4.1. **Effect pathway methodology.**



Source: Authors based on Markandya et al., 2007.

Selection of the Most Polluted Areas of Poland for the Benefit Cost Analysis

100 percent of the population in Poland is exposed to annual average concentrations of $PM_{2.5}$ above the WHO guideline of 10 µg/m^3, and more than 99.6 percent – to concentrations above 15 µg/m^3 (van Donkelaar et al., 2016). Recent monitoring data confirms that a significant part of the urban population in Poland is exposed to even higher concentrations (see Chapter 2). Table 4.1 shows ambient annual average concentrations of $PM_{2.5}$ in the most polluted urban centers in Poland, exposed populations and cost of ambient air pollution (AAP) estimated in Chapter 2 of this report. The health burden attributed to ambient air pollution is estimated both in physical (avoided mortality and morbidity) and monetary terms for the selected most polluted voivodeships.

Table 4.1. Measured $PM_{2.5}$ annual average exposure for the most polluted urban areas in Poland

Voivodeship	Metropolitan area	Average annual measured $PM_{2.5}$ concentration, µg/m3	Population, thousands	Cost of AAP, million US$
śląskie	Górnośląska	31	4,559	5,256
mazowieckie	Warszawska	22	5,366	6,847
małopolskie	Krakowska	32	3,382	3,085
dolnośląskie	Wrocławska	23	2,904	3,159

Source: Inspekcja Ochrony Środowiska, 2017; Statistical Yearbook of the Republic of Poland 2017[34]; Authors' estimate

In many urban areas, average annual concentrations of $PM_{2.5}$ are well above the WHO Air Quality Guideline (10 µg/m^3) and the less stringent EU (Polish) Limit Value (25 µg/m^3). The four voivodeships in Table 4.1 were identified by the Supreme Audit Office in Poland (SAO, 2014) as the voivodeships with the most serious ambient air pollution situation. The ambient air pollution and the Anti-Smog Resolutions for those voivodeships were subsequently analyzed in SAO (2018).

Targeting - Emission Reduction Requirements for Poland

In its Clean Air Programme for Europe (COM (2013)918 final), the European Commission has laid out a comprehensive approach to improve air quality in Europe. It contains provisions for regular tracking of the progress towards the programme objectives by 2020 and every five

34 Available at: https://stat.gov.pl/en/topics/statistical-yearbooks/statistical-yearbooks/statistical-yearbook-of-the-republic-of-poland-2017,2,17.html

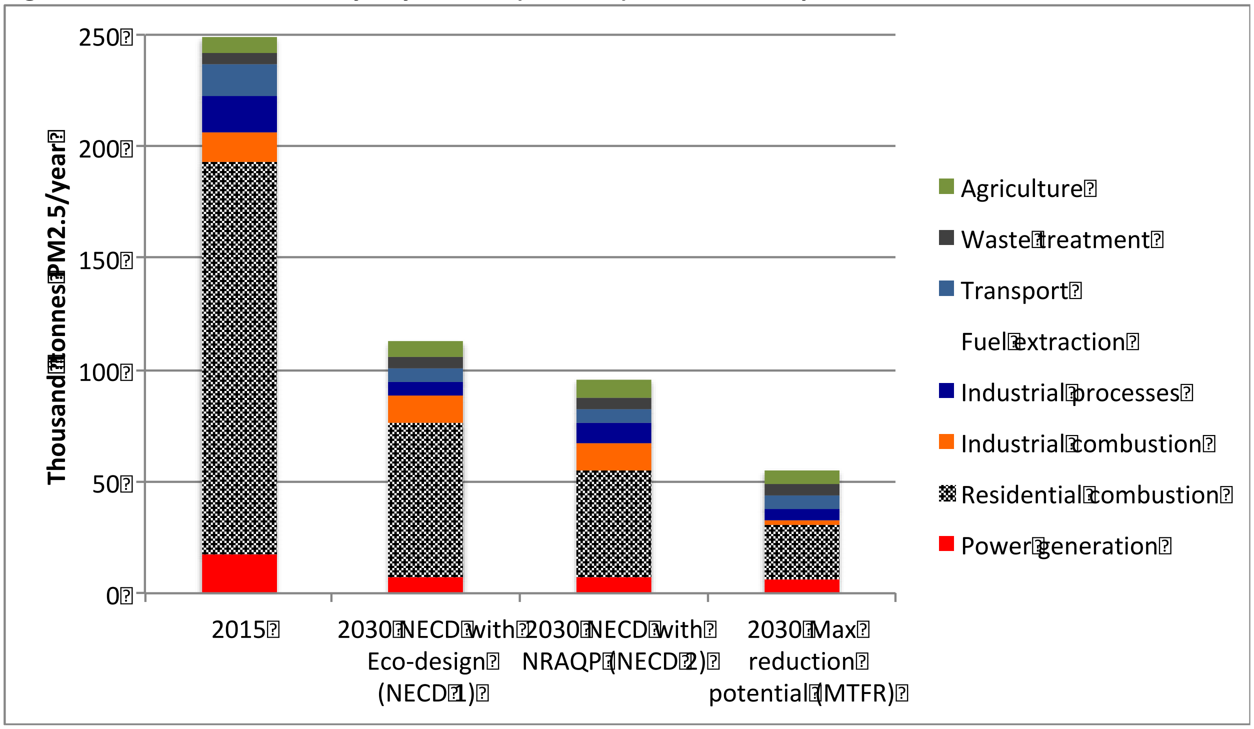
years thereafter. The National Emissions Ceiling (NEC) Directive sets national reduction commitments for five air pollutants including fine particulate matter, which leads to significant negative impacts on human health and the environment. The NEC Directive contains, as an essential element, politically agreed emission reduction requirements (ERRs) that specify the percentage by which national emissions need to be reduced by the year 2030 relative to the 2005 level. The GAINS model (described in Chapter 3) was used to estimate corresponding ERRs for Poland. The emission reduction requirement estimated by GAINS for Poland is 58% of its $PM_{2.5}$ emissions by 2030 compared to 2005, or 134 kilotons annually down to the target level of 104 kilotons of $PM_{2.5}$ emissions annually. According to the GAINS analysis, and supported by other analyses, the majority of abatement effort falls on residential combustion (about 50 percent nationally). Reductions in this sector will lead to significant reduction of health risk attributed to air pollution. However, based on the GAINS simulations, southern Poland will be one of two areas in Europe with significant exceedances of the WHO guideline (10μg/m^3) value by 2030 even after the ERR is met (Amann et al 2017).

Therefore, achievement of the national emissions reduction target does not automatically guarantee compliance with WHO air quality guidelines everywhere in the country. The problem of hot spots such as in southern Poland will have to be addressed by a sub-national analysis with a particular focus on the most polluted urban areas, where transport emission reductions will also play an important role in addition to residential combustion.

A comprehensive analysis of AAP in Poland should be the foundation of Poland's air quality management. In this context, GAINS provides an example of the sort of considerations that should be taken into account. The analysis presented in Chapter 3, of $PM_{2.5}$ emissions by source and their contribution to the annual average $PM_{2.5}$ concentration, was conducted at the national level, and was not area specific, whereas the current chapter attempts to expand this analysis to the voivodeship level.

Chapter 3 advances the understanding of emissions inventories in Poland and updated the emissions inventory to make it more consistent with the reported annual average ambient $PM_{2.5}$ concentrations. In Poland, more than half of $PM_{2.5}$ total emissions originate from the combustion of solid fuels in the residential sector, due to the dominance of old, small combustion devices without emission controls. Although only 20% of all coal is used for residential combustion, this generates 80% of all coal-related $PM_{2.5}$ emissions nationally (Figure 4.2). Similarly, all $PM_{2.5}$ from biomass combustion comes from the residential sector, although only half of all biomass is used there. Figure 4.2 presents existing $PM_{2.5}$ emissions by sector in 2015 and projected emissions up to 2030 for three scenarios examined in this chapter (and in chapter 3) as calculated by the GAINS model.

Figure 4.2. $PM_{2.5}$ emissions by key sectors (kilotons) in 2015 and up to 2030.



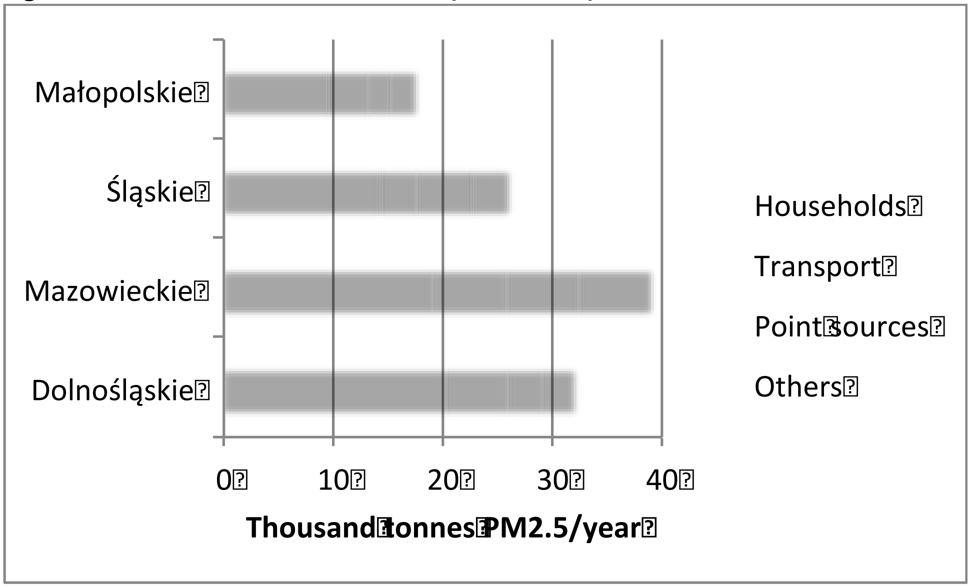
Source: Approximated by the authors.

The NECD compliant scenario with Eco-design implementation (NECD 1) will reduce $PM_{2.5}$ emissions in Poland by 55% from the 2015 baseline. Under the second scenario (NECD 2) $PM_{2.5}$ emissions are reduced by 61%. If the scenario with maximum emission reduction potential (MTFR) is implemented, $PM_{2.5}$ emissions are reduced by 78%. Only the MTFR scenario guarantees compliance with WHO annual average ambient $PM_{2.5}$ guideline value (10µg/m^3) in the most polluted voivodeships in southern Poland (Figure 4.2).

Disaggregation and Source Apportionment of National Inventories to Voivodeships

A recent analysis conducted by the Polish Supreme Audit Office (SAO 2018) presents emissions in the most polluted voivodeships and describes the deficiencies of the regional Air Quality Plans and Anti-Smog Resolutions. The same study presents emission inventories for the most polluted voivodeships. The highest annual $PM_{2.5}$ emissions are estimated in mazowieckie voivodeship (39,000 tonnes), with the lowest in małopolskie (18,000 tonnes). The share of emissions from household combustion is at 50-65% in all four of these voivodeships (Figure 4.3).

Figure 4.3. **$PM_{2.5}$ emission inventories by voivodeship**

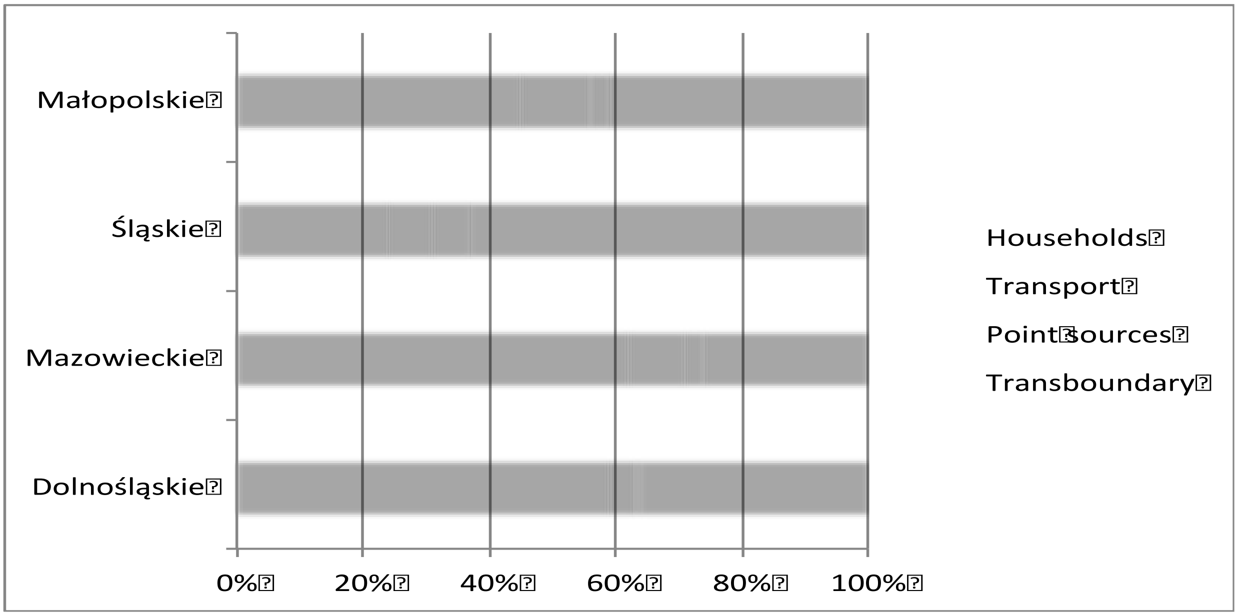


Source: Estimated by the authors based on SAO (2018).

The primary tool to identify the sources that are responsible for the exceedances of the EU Limit Values and WHO guidelines, are source apportionment studies. SAO (2018) has quantified source apportionment for the origins of air pollution in cities and regions. In (SAO, 2018), both the spatial (most polluted voivodeships and cities) and sectoral (households, transport, point sources, transboundary) contributions are quantified for Poland. Source apportionment estimations for four voivodeships analyzed in this chapter are shown in Figure 4.4 (SAO, 2018) and form the basis for the benefit–cost analysis of interventions to achieve air quality improvements in Poland.

National source apportionment studies report that the contribution of household combustion to air pollution is at about 60% in dolnośląskie and mazowieckie voivodeships, and about 45% in małopolskie voivodeship. In śląskie voivodeship it is at about 24%, most of the pollution is explained by transboundary sources there. In the three other voivodeships transboundary sources are responsible for 25-40% of all emissions. The contribution of transport is highest in małopolskie and mazowieckie voivodeships (at about 10%). The share of point sources (high stack power generation and industry sources) is the highest at śląskie voivodeship (6%).

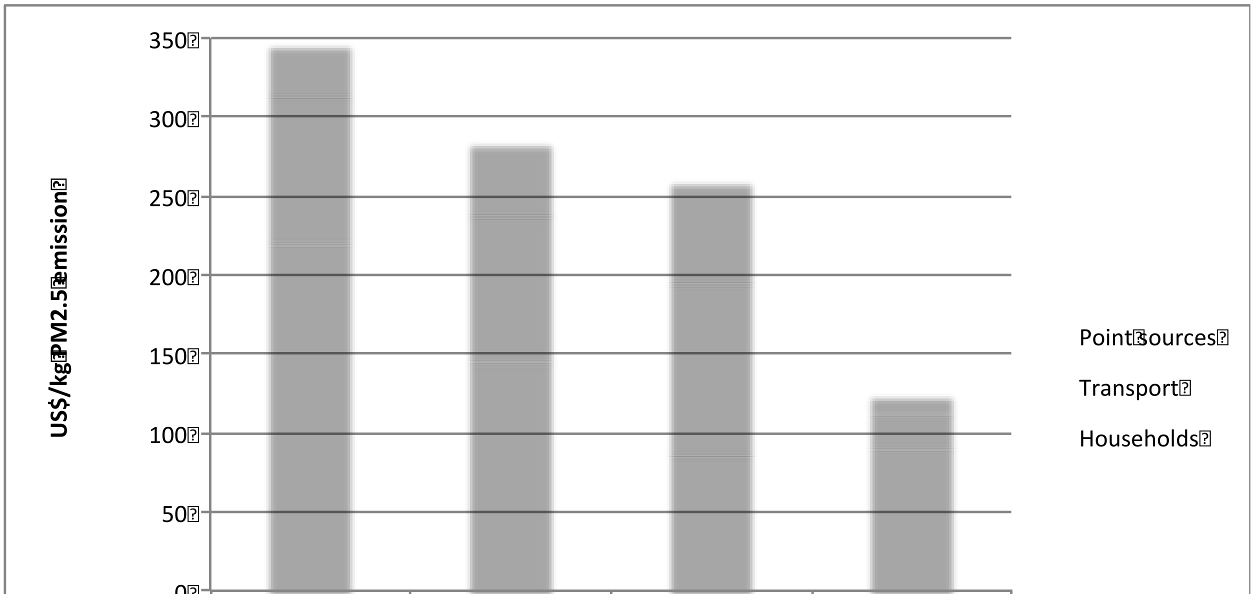
Figure 4.4. **Source apportionment by voivodeship**



Source: SAO, 2018

Using emission inventories and source apportionment studies, available for the most polluted voivodeships (SAO, 2018), the emission pathway approach allows estimation of the cost of health damage from AAP per tonne of $PM_{2.5}$ emissions (also referred to as cost of AAP per tonne of $PM_{2.5}$) for each sector and voivodeship (Figure 4.5). The emission pathway approach provides a site/source specific result that allows application of benefit-cost analysis to prioritize emission reduction interventions in Poland. Health benefits of air pollution control were estimated for site-specific interventions to reduce $PM_{2.5}$ emission using results of the cost of air pollution presented in chapter 2. Household combustion emissions are the cause of the most significant damage per tonne of $PM_{2.5}$ emissions in all voivodeships except śląskie where health damage per ton of $PM_{2.5}$ emissions from transport is comparable to the residential sector and point sources are also significant (Figure 4.5). SAO (2018) cites similar estimates of cost of AAP per tonne of $PM_{2.5}$ obtained from (AEA Technology Environment, 2005) for $PM_{2.5}$ pollution reduction interventions based on application of the ExternE model in 2002. While still valuable, these estimates are outdated, and are not site- or source-specific. If converted to US$, the estimate in (AEA Technology Environment, 2005) is US$35-100 per kg of $PM_{2.5}$ emissions, which is within the range of magnitude of the estimates in this report (Figure 4.5).

Figure 4.5. Estimated cost of AAP per kg of $PM_{2.5}$ emissions by voivodeship



	Mazowieckie	Małopolskie	Śląskie	Dolnośląskie
Point Sources	31	44	62	10
Transport	93	92	109	22
Households	222	147	88	92

Source: Estimated by authors

Benefits and Costs of Reducing Air Pollution from Residential, Transport and Point Sources

Investment decisions on interventions to reduce air pollution should consider the health impacts and costs of these health impacts attributed to this air pollution. The tool that allows comparison of such interventions is cost-benefit-analysis. Policies and measures for reducing environmental pollution generally require additional costs for industry and consumers. Thus, it is important for the acceptance of the measure to show that the benefits, for example reduced health risks, outweigh or justify the costs. The benefit can be expressed as avoided health costs. To calculate the avoided health costs, two scenarios are needed: a baseline scenario, which describes development without the measure or policy and a scenario including it. Then the impacts occurring for the two scenarios are calculated. The difference between the impacts is monetized; this gives the avoided health costs or benefits (provided that the impacts of the scenario with the measure are lower than for the baseline scenario). These benefits can then be compared with the implementation costs of the policy or control measures. If benefits are larger than costs and the benefit-cost ratio is above one, the policy or measure is thought to be beneficial for society's welfare.

BCA of Interventions in the Residential Sector

Residential combustion is the major source of health damage per ton of $PM_{2.5}$ emissions in most of the affected voivodeships. The government of Poland's objective is to develop a program to reduce air pollution and improve energy efficiency through old boilers replacement and thermal retrofits of single-family buildings (SFBs) (World Bank, 2018). Thermal retrofits of SFBs can lower the heat demand of SFBs and the capacity of boilers and save fuel costs. So, Poland can reduce air pollution and improve energy efficiency in SFBs through the replacement of non-compliant solid-fuel boilers with coal and gas boilers, heat pumps, and other heating systems that meet regulatory and building codes, coupled with thermal retrofits of SFBs. The cost-effectiveness of various interventions to reduce air pollution from the residential sector in Poland is presented in Table 4.2.

Table 4.2. Cost (PLN) and Emission Reductions from Replacement of Old Solid-Fuel Boilers with Alternative Technologies and Thermal Retrofits of SFBs

Costs and Emission Reductions of Replacement of Old Coal Boiler and Thermal Retrofit of SFBs											
	Replacement with ECO-design coal boiler	ECO-design coal boiler+partial thermal retrofit of SFB***	ECO-design coal boiler + full thermal retrofit of SFB****	Switching from old coal to gas boiler	Gas boiler + partial thermal retrofit of SFB***	Gas boiler + full thermal retrofit of SFB****	Switching from old coal boiler to heat pump	Heat pump + partial thermal retrofit of SFB***	Heat pump + full thermal retrofit of SFB****	Partial thermal retrofit only***	Full thermal retrofit only****
Annual Fuel savings (GJ)	- 14.7	57.5	98	12.6	72.8	106.5	112.0	128.4	137.6	42.4	89.6
Annual fuel cost savings (PLN)*	- 1,857	501	1,825	-3,794	-584	1,219	-2,500	141	1,624	995	2,101
Total investment** (PLN)	13,500	38,500	63,500	7,500	32,500	57,500	25,000	50,000	75,000	25,000	50,000
Annual reduction in particulate emissions (kg)	95	97	98	100	100	100	100	100	100	28	60
Annual reduction in CO2 emissions (tons)	- 4.1	1.9	5.3	2.4	5.5	7.3	1.1	4.8	6.9	2.7	5.7

+ The automatic-fed coal boiler consumes more coal and replaces the use of wood. It also consumes electricity for its operations.

* The new coal boiler requires higher priced coal; gas and electricity are more expensive than coal.

** A 5-10 kW automatic Ecodesign coal boiler costs about 9,000 PLN; a gas boiler costs about 4,000 PLN; and a heat pump costs about 20,000 PLN. This is in comparison to about 2,500 PLN for a "smoker" or manually fed boiler (total investment Includes cost of duct work and installation cost for new boiler).

*** Partial retrofits include wall insulation and modernization of the central heating system components.

**** Full retrofits include wall, roof, and floor insulation, and modernization of the central heating system components.

Source: World Bank, 2018

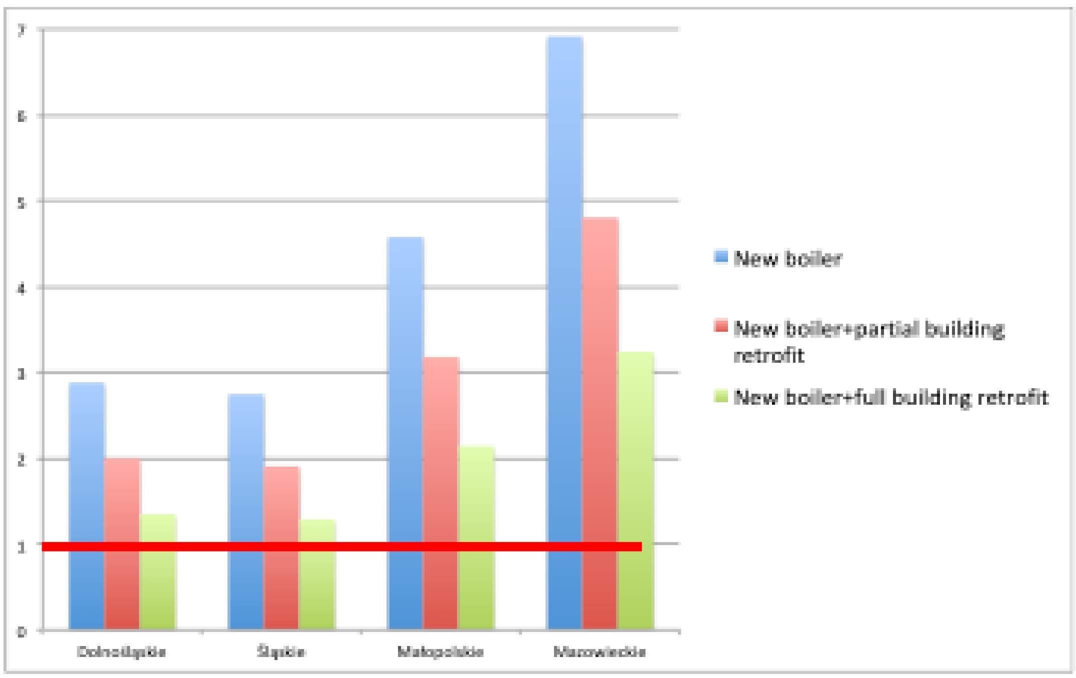
The emission reduction scenario assumes a gradual shift to gas boilers, and an increase of municipal heating connections. Also, based on GAINS projections, less than 5% of households will choose to install heat pumps by 2030. Then estimated benefit-cost ratios (BCRs) of replacement of old boilers and thermal retrofit of houses in the residential sector are shown in Table 4.3 and Figure 4.6. For all interventions a 10-year life cycle and 10% capital cost are assumed.

Table 4.3. Costs, benefits and BCR of interventions in residential sector

Voivodeship	Replacement of boilers			Replacement of boilers and partial SFBs retrofit			Replacement of boilers and full SFBs retrofit		
	Annualized investment cost, US$ million	Avoided damage, US$ million	BCR	Annualized investment cost, US$ million	Avoided damage, US$ million	BCR	Annualized investment cost, US$ million	Avoided damage, US$ million	BCR
dolnośląskie	18	52	2.9	27	53	2.0	39	53	1.3
małopolskie	19	89	4.6	28	90	3.2	42	90	2.1
mazowiecke	23	157	6.9	33	161	4.8	50	161	3.2
śląskie	29	80	2.7	43	81	1.9	63	81	1.3

Source: Estimated by authors

Figure 4.6. Estimated BCRs of old boilers replacement and thermal retrofit of houses in residential sector



Source: Estimated by authors

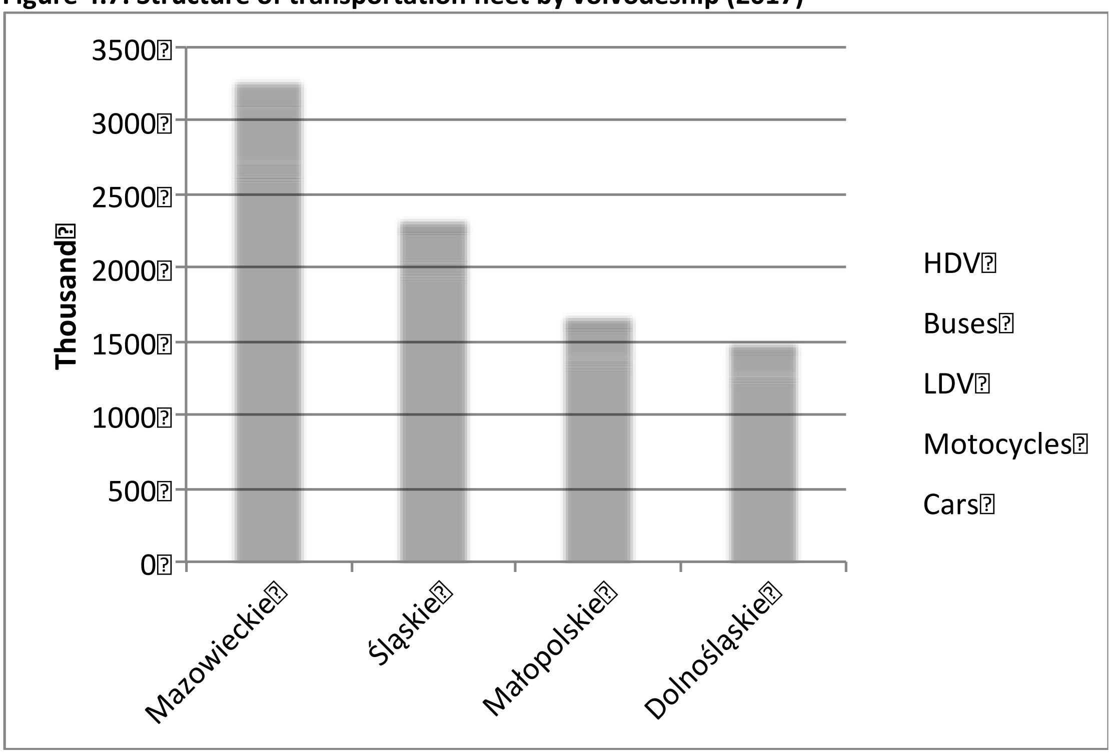
BCA confirms that all interventions to reduce pollution in the residential sector are economically viable. Interventions in mazowieckie and małopolskie voivodeships have the highest BCR and should have priority. Also, these interventions have similar BCRs for the three emission scenarios analyzed.

BCA of Interventions in the Transport Sector

Transport is often an important source of ambient air pollution, especially in urban areas in many parts of the world. According to the Polish Automotive Industry Association (PZPM) the average age of passenger cars in Poland in 2016 was 15 years (PZPM, 2018). In 2017 the average age of over 1 million imported used cars was about 14 years. Older cars do not meet current standards related to maximum emission limit values of harmful substances into the atmosphere (Dzikuc et al. 2017). EU emissions standards apply to most new vehicles (cars, trucks, trains, buses, agricultural machinery, boats). The impact of transport on pollution is potentially higher in areas with a high density of transport.

Figure 4.7 shows the categories of road vehicles in the most polluted voivodeships. Private cars dominate the fleet. It is reported that cars are responsible for about 63% of all $PM_{2.5}$ emissions in transport (Dzikuc et al. 2017).

Figure 4.7. Structure of transportation fleet by voivodeship (2017)



Source: RAPORT PZPM 2018
Note: HDV for heavy-duty vehicles; LDV for light duty vehicles

Interventions in the most polluted voivodeships include numerous measures to reduce transport pollutions. Most of the interventions address fleet regulation, traffic management, and age of vehicles. However, these interventions are not adequate. Recognizing the growing contribution of transport to air pollution in urban centers and following the requirements of the

EU Directive 2014/94/EU of 22 October 2014 on the deployment of alternative fuels' infrastructure, Poland adopted the Act on Electromobility and Alternative Fuels in 2018[35]. The Act is intended to promote electric vehicles and alternative fuel vehicles. In one scenario, by 2025 the number of electric cars of all types could reach as many as 1 million (about 550,000 battery cars and approx. 400,000 plug-in hybrid vehicles). In 2030 there could be as many as 3 million electric cars (1.9 million battery electric vehicles and 1.1 million plug-in hybrids respectively) and in 2050, 16.5 million electric cars, of which 13.7 are battery cars and 2.9 are plug-in-hybrids (Korolec & Bolesta, 2018). Also, the Government is enforcing compliance with higher Euro standards. The Government announced in May 2018 that more effective controls will be carried out during obligatory car technical tests.

Based on the transportation fleet scenarios in (Dzikuc et al., 2017) and the GAINS model projections for the number of cars, the following scenarios for benefit-cost analysis were formulated:

1. By 2025 the structure of the automobile fleet will change i.e., 10% of the oldest cars will be substituted with new ones that meet at least Euro 5 standard;
2. The plan for electromobility in Poland is implemented by 2025: 1 million electric and hybrid vehicles (EVs) registered;
3. Both (1) and (2) are implemented.

Following the recommendation in (Dzikuć et al., 2017) it is assumed that in the most polluted voivodeships 10% of the cars met the standard EURO VI, 20% met the standard EURO V, 15% of EURO IV, 20% of EURO III, 20% of the standard EURO II and 15% cars met the standard EURO I. In contrast, about 30% of cars are powered by diesel engines and about 55% by gasoline (Dzikuć et al., 2017). Table 4.4 presents estimated $PM_{2.5}$ emissions in the base year i.e., 2015, by the most polluted voivodeships.

Table 4.4. Estimated annual $PM_{2.5}$ emissions by voivodeship (2015)

EU Emission Standards for Passenger Cars				Number of cars				$PM_{2.5}$ emissions, tonnes			
Stage	Date	$PM_{2.5}$		dolnośląskie	mazowiecke	śląskie	małopolskie	dolnośląskie	mazowiecke	śląskie	małopolskie
		g/km	km/yr								
Compression Ignition (Diesel)			16000								
Euro 1	1992.07	0.14		56	117	87	60	125	261	196	134
Euro 2	1996.01	0.08		74	155	116	80	95	199	149	102
Euro 3	2000.01	0.05		74	155	116	80	59	124	93	64
Euro 4	2005.01	0.025		56	117	87	60	22	47	35	24

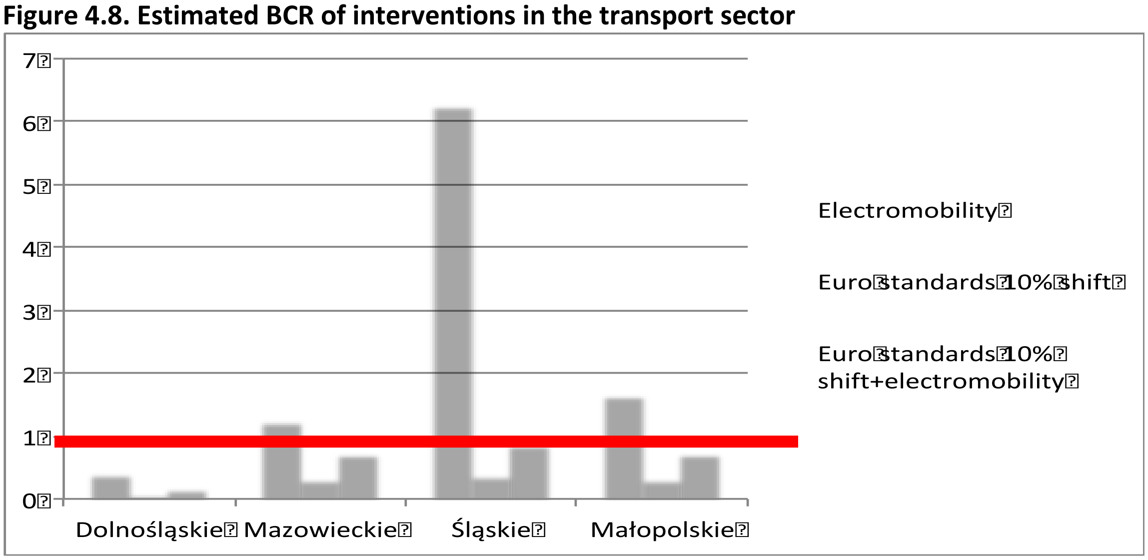
35 http://www.klgates.com/act-on-electromobility-and-alternative-fuels-enters-into-force-02-09-2018/

Euro 5	2009.09 b	0.005		74	155	116	80	6	12	9	6
Euro 6	2014.09	0.005		37	78	58	40	3	6	5	3
Positive Ignition (Gasoline)			16000								
Euro 1	1992.07	0.09		119	249	186	128	161	338	253	174
Euro 2	1996.01	0.01		158	331	248	170	13	27	20	14
Euro 3	2000.01	0.01		158	331	248	170	13	27	20	14
Euro 4	2005.01	0.01		119	249	186	128	9	20	15	10
Euro 5	2009.09 b	0.005		158	331	248	170	13	27	20	14
Euro 6	2014.09	0.005		79	166	124	85	6	13	10	7

Source: Estimated by authors using https://www.transportpolicy.net/, Dzikuc et al. 2017, Ligterink , 2017.

Then the costs and benefits of interventions (1) and (3) are estimated using EU studies on the costs of emission reduction technologies for cars and heavy-duty vehicles (GerMan 2012, Posada et al., 2016). Additionally, it is assumed that to achieve NECD targets, EVs will phase out diesel cars. Only the cost of establishing 6,000 new charging stations as planned in the Act is applied to the electromobility scenario. As estimated by Sipinski and Bolesta (2018), the cost of each charging station is assumed to be US$20,000 (15 years life cycle, 10% cost of capital). Sipinski and Bolesta (2018) also suggest that EVs will have higher prices than cars with combustion engines, but this analysis disregards this higher price as several recent studies estimate the total cost of EV ownership and show that, over a vehicle's life-time, it is lower than, or comparable to, the cost of a vehicle with a combustion engine (Palmer et al., 2018; Palinski 2017). The estimated BCRs of the three pollution reduction measures in transport are shown in Figure 4.8.

Figure 4.8. Estimated BCR of interventions in the transport sector



Source: Estimated by authors

The BCR of the electromobility plan is greater than 1 in three voivodeships for all three GAINS emission scenarios. This intervention is especially efficient in śląskie voivodeship, where electromobility is also viable together with a general improvement of the car fleet structure. It is important to mention that only pollution reduction benefits of electromobility in urban centers are considered in BCA. Many additional co-benefits of electromobility are not quantified, including: (i) strengthening of electricity transmission and distribution grids; and (ii) developing of EV manufacturing: create 50,000 new jobs by 2030 and boost GDP growth by 0.3% (Korolec & Bolesta, 2018).

BCA of Interventions to reduce air pollution from Point Sources

Reduction of high-stack point sources of pollution (power generation and industry) in Poland is required by the EU Directive on ambient air quality and cleaner air for Europe and the EU Directive on industrial emissions. Poland has a National Transitional Plan to reduce emissions to meet EU requirements. A significant share of coal in the Polish energy balance predetermines most of the PM emissions from point sources. Compared to other EU member states, Poland has substantially larger reserves of hard coal and lignite and uses them for electricity production. Almost half of Polish electricity production in 2015 (i.e., 79.9 TWh or 48.4%), was generated at hard coal-fired power plants and 52.9 TWh (or 32.1%) at lignite-fired power plants[36]. Installed capacity of coal-fired power plants is 28.6 GW, among which the highest air pollutant emissions are from the Bełchatów (lignite) power plant in Central Poland, the biggest coal power plant in Europe, followed by Pątnów II (lignite) power plant in Central-Western Poland near Poznań, and Rybnik power plant (hard coal) in Upper Silesia Industrial District region (Ministry of Economy, 2013; RAP, 2018).

As confirmed by source-apportionment studies in Poland, specifically for Warsaw and Krakow (Holnicki et al., 2017, Samek et al., 2017), a substantial part of $PM_{2.5}$ pollution is contributed by secondary aerosols. These aerosols are described as regional scale pollution and long-range transport species. They originate from high stack point sources, and local measures to abate them cannot be fully effective. National level programs are needed to address this type of pollution.

Thus, this report assumes that dispersion of pollution from high stack sources occurs in each of the voivodeships proportionally to the national pollution reduction, as estimated by GAINS. The interventions that have to be implemented by all point sources include in-furnace control -

[36] https://euracoal.eu/info/country-profiles/poland/

limestone injection, enforcement of low sulfur coal (0.6% S) use, wet flue gases desulfurization (retrofitted) and wet flue gases desulfurization. All these interventions will be implemented in all three GAINS scenarios to meet NECD targets and achieve WHO air quality guidelines.

The estimated BCRs of interventions to reduce point source pollution are presented in Table 4.5 and Figure 4.9. Costs of interventions are adopted from the GAINS study and adjusted to 2016 with the Euro area GDP deflator.

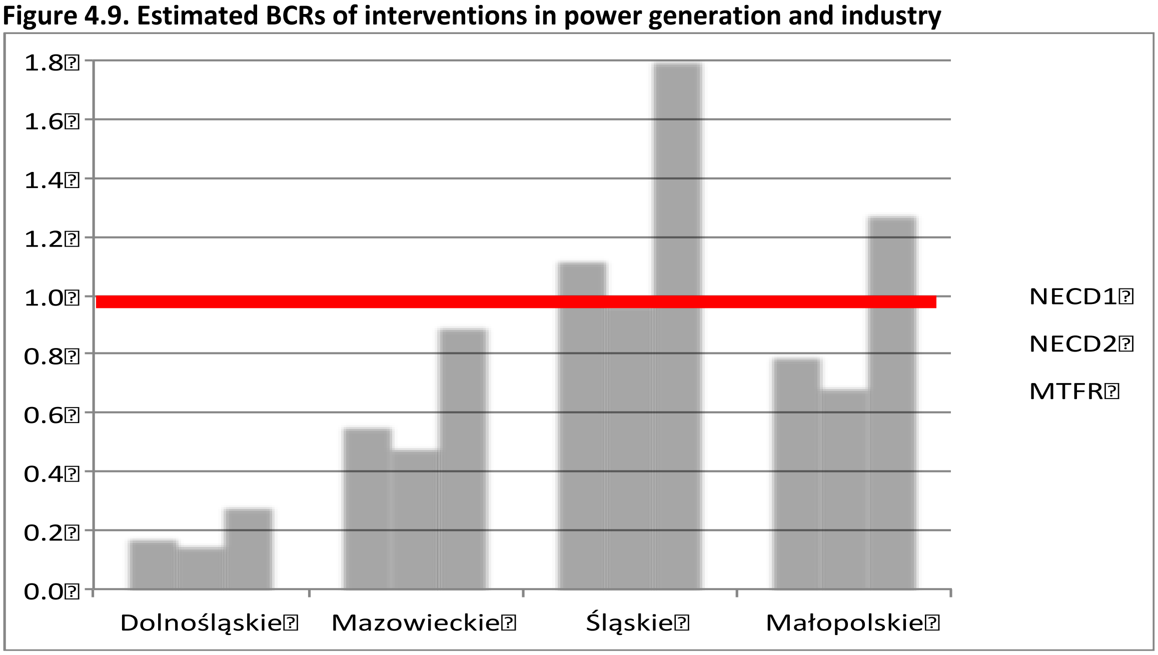
Table 4.5. Annual Costs, benefits and BCRs of interventions for power generation, and industry

	Avoided damage, US$ million			Cost, US$ million			BCR		
	NECD1	NECD2	MTFR	NECD1	NECD2	MTFR	NECD1	NECD2	MTFR
dolnośląskie	0.01	0.01	0.02	0.08	0.08	0.08	0.2	0.2	0.3
mazowiecke	0.09	0.08	0.15	0.17	0.17	0.17	0.6	0.5	0.9
śląskie	0.14	0.12	0.23	0.13	0.13	0.13	1.1	1.0	1.8
małopolskie	0.04	0.04	0.07	0.05	0.05	0.05	0.8	0.7	1.3

Source: Estimated by authors

BCRs of interventions are greater than 1 in śląskie voivodeship for all three scenarios, and in małopolskie for the MTFR scenario. It is important to note that results in this sector are uncertain due to the transboundary nature and uniform character of emissions from high-stack point sources.

Figure 4.9. Estimated BCRs of interventions in power generation and industry



Source: Estimated by authors

Summary

This chapter presents analyses of the costs and benefits of interventions to reduce ambient air pollution(AAP) in three sectors in mazowieckie, śląskie, małopolskie and dolnośląskie voivodeships where AAP costs per capita are among the highest in the country. These voivodeships have also been identified as priorities in the national air quality management program. The analyses focus on three NECD-compliant scenarios and are based on emission inventories and source apportionment analysis for the four voivodeships.

The chapter demonstrates how cost-benefit analysis can be used to target pollution reduction interventions in the areas of highest health risk, and potentially bring air quality into compliance with EU Limit Values and eventually WHO air quality guidelines. Specifically, the cost-benefit analysis shows that interventions in the residential sector generally yield the highest benefit-cost ratios (BCRs) compared to interventions in the transport sector and for point sources, indicating that interventions in the residential sector be given the highest priority. However, there are differences in BCRs between the voivodeships, which suggest that mazowieckie and małopolskie voivodeships should have the highest priority as they yield the highest benefit-cost ratios. Preliminary analysis indicates that electromobility should also have high priority for reducing emissions in śląskie voivodeship.

Chapter 5. Institutional and Policy Frameworks

This chapter reviews the institutional and policy frameworks for air quality management (AQM) in Poland. It examines aspects of the regulatory context and the national and regional organizational structures for AQM. It discusses some of the issues related to the complex, decentralized system of air quality management in Poland. Furthermore, it discusses the design and implementation of tools for air quality management planning at the regional level, notably Air Quality Plans. The chapter also provides recommendations for addressing areas that could be enhanced. It is based on desk reviews and limited interviews and recognizes that an exhaustive analysis of the efficiency and effectiveness of the design and implementation of institutions and policies for air quality management in Poland will require additional information and data, obtained through stakeholder consultations such as interviews, workshops, surveys, focus groups and other avenues.

Polish Regulatory Context for Air Quality Management

The European Commission adopted the Clean Air Policy Package in 2013, including a Clean Air Programme for Europe (CAPE), which sets objectives for 2020 and 2030 and accompanying legislative measures. By 2030, the Clean Air Policy Package aims to reduce negative health impacts from air pollution by 52% compared to 2005. As an EU Member State, Poland must comply with the air quality requirements set by EU legislation. Thus, EU legislation is transposed to Polish laws and regulations. The suite of Polish legislation is complemented by national strategies and programs, which jointly provide the regulatory basis for air quality management at national, regional (voivodeship) and local levels. Summaries of relevant EU Directives and their transposition to Polish legislation, and some key legislation related to air quality management in Poland are provided in Table D.1 and Table D.3 of Annex D.

The Environment Protection Law, enacted in April of 2001, is a foundational piece of national legislation that regulates issues related to air quality management in Poland. The Law transposes the provisions of the EU Directive on Ambient Air Quality and Cleaner Air for Europe related to air quality standards – namely, their introduction, monitoring and reporting of air quality, the assessment of air quality in zones, and the requirement for Air Quality Plans and/or Short-Term Action Plans. National strategies determine the goals of the country’s policy, and although without legal force, they set the directions at a national level for air quality management in Poland. Two strategies specifically address air pollution:

- The National Air Quality Plan

- The Government's "Clean Air" Programme

National Air Quality Plan (NAQP)- The foundation of current air quality management in Poland is the NAQP of 2015, which sets goals and directions for actions that should be included in all Air Quality Plans prepared at the sub-national level. The introduction of NAQP can be considered a key step in air quality management development in Poland since it represented the first time that the strategic actions for air quality improvement across the country were discussed in a comprehensive way and in one overarching document. The organizational scheme for the NAQP development and implementation is presented in Figure D.1 in Annex D.

A key challenge identified by the NAQP is to decrease the concentrations of PM_{10}, $PM_{2.5}$, B(a)P, NO_2 and O_3 to levels not exceeding air quality standards. According to the NAQP, individual residential heating (by annual air quality assessments in Voivodeships) is the prevailing reason for exceedances of air quality standards throughout most of the country: in 2013 it was responsible for 88%, 87% and 98% exceedances of PM_{10}, $PM_{2.5}$ and B(a)P, respectively.

Clean Air Programme (CAP) - In response to a period of numerous and severe exceedances of air quality standards, in January of 2017 the Economic Committee of the Council of Ministers announced its recommendations of actions to be taken to improve air quality, which the Council of Ministers adopted in the form of a "Clean Air" Programme. Furthermore, in March of 2018 the Plenipotentiary of the Prime Minister for the "Clean Air" Programme was appointed with the task of implementing the CAP. The Plenipotentiary was also appointed as the head of the NAQP Steering Committee, thus broadening the scope of the Committee's activities to also cover the CAP.

The CAP consists of 15 detailed recommendations to implement the NAQP (summarized in Table D.2 of Annex D). Accomplishments with respect to implementation of the recommendations of the CAP have been mixed. Notwithstanding, the government has made notable achievements in passing new legislation and strengthening support for programs to address air pollution primarily from the residential sector, and from the transport sector, which are discussed below. Following are four of the key recommendation areas in the CAP that address air pollution from the residential and transport sectors.

i. Technical requirements for solid fuel boilers
ii. Regulations on quality standards for solid fuels –.
iii. Prioritization of resources to support actions to improve air quality
iv. Incentives for low-emission transport

Technical requirements for solid fuel boilers - in 2017 the government adopted regulations (JoL. 2017, item 1690)[37], which introduced, for the first time, technical requirements for small-scale solid fuel boilers used in the residential and service sectors. The regulation prohibits the sale of the more polluting no-class, class 3 and class 4 boilers effective July 2018. Furthermore, only class 5 boilers meeting more stringent emission requirements may be used in new installations. The class 5 boilers have similar maximum emission requirements as stated in the EC Ecodesign Regulation[38] with the exclusion of NO_x. The following types of installations are exempt from the requirements of the Ecodesign Regulation: (i) boilers generating heat exclusively for providing hot drinking or sanitary water; (ii) boilers for heating and distributing gaseous heat transfer media such as water vapor or air; (iii) solid fuel cogeneration boilers with a maximum electrical capacity of 50KW or more; and (iv) non-woody biomass boilers. It will be needful to address legislative gaps that could allow boiler manufacturers to bypass the requirements of the law in particular in relation to exempt installations (e.g. by selling no-class coal boilers originally designed for building heating as hot water heaters). Furthermore, penalties to deter such behaviors could be put in place and enforced.

Regulations on solid fuel quality standards – Following amendment of the Act on the fuel quality monitoring and control system (JoL 2006, No. 169, item 1200) – which previously addressed liquid and gaseous fuels only – to include solid fuels used by households and small consumers, the government adopted a regulation on quality requirements for solid fuels[39] on September 27, 2018. The new regulation sets standards including maximum ash, sulfur and moisture contents, minimum calorific value for coal, briquettes, pellets, coke and coal slack. The regulation prohibits the sale of low quality coal fines (grain size of 1 mm-31.5 mm) effective June 2020. However, enforcing the ban on its use in households may be challenging and the government will need to take strict measures, including incentives to enforce the ban. While the fuel quality standards are clearly a positive development, there is room to make them more stringent. For example, the new regulations specify up to 1.7% sulfur content for coal use for small consumers. By comparison, in some other coal-consuming countries, sulfur content for all consumers is: Czech Republic (0.42-0.43%); Turkey (0.8-1.0%); and Germany (0.45-1.8%).[40] The Polish government could take steps to further reduce the sulfur content of solid fuel in the short- to medium-term.

[37] Regulation of the Minister of Development and Finance on Solid Fuel Boilers (Journal of Laws 2017, item 1690)

[38] Effective January 1, 2020, solid fuel boilers in EU Member States must meet the requirements of the EC Ecodesign Regulation 2015/1189 of 28 April 2015), which implements the Ecodesign Directive 2009/125/EC. The Ecodesign Directive established a framework for setting ecodesign requirements for energy-related products.

[39] Regulation of the Minister of Energy on Quality Requirements for Solid Fuels (Journal of Laws 2018, item 1890)

[40] https://euracoal.eu/library/annual-reports/

Support for replacement of old boilers and improvement of energy efficiency of residential buildings – The government adopted a Clean Air Priority Programme in June 2018, aimed at improving energy efficiency and controlling air emissions from existing and newly built single-family buildings by co-financing replacement of boilers, changes to cleaner fuels and thermal insulation through subsidies, preferential loans and combinations thereof, as well as tax incentives related to thermo-modernization. The Programme, with a budget of PLN 103 billion, will be implemented over a 10-year period (2018-2029), by the National Environmental Protection and Water Management Fund in collaboration with provincial funds for environmental protection and water management. Recognizing the enormity of the scale of needs, the government anticipates EU funding for implementation of the Programme in addition to local funding.

Incentives for low-emission transport – The CAP calls for the use of tax mechanisms, including low excise duty rates for hybrid cars and exemption of electric cars from excise taxes, to introduce low-emission transport. In January of 2018, the government enacted a law on electromobility and alternative fuels (JoL 2018, item 317) to implement the national Electromobility Development Plan, launched in March of 2017. The Plan envisages 1 million electric cars in Poland by 2025 and provides for a system of incentives including excise exemptions for electric cars and a temporary excise exemption for plug-in hybrids; exemption of electric cars and plug-in hybrids from parking fees and permitting them to drive on bus lanes; and larger depreciation write-offs for electric cars and hybrids compared to regular vehicles. The law introduces the creation of low-emission zones by municipal governments in densely built-up areas. Implementation of the law provides potential opportunities for economic development, in addition to environmental improvements. Given the relatively old age of Poland's vehicle fleet and that people of lower economic status are more likely to drive older vehicles, the government could consider understanding the distributional impacts of implementing low-emission initiatives.

Organizational Structure for Air Quality Management

Poland's legal framework for managing air pollution is complex and decentralized, guided by the overall four-tier government administration (national, voivodeship, powiat, gmina levels). This organizational structure requires the interaction of many stakeholders including administrative bodies from the environment and other sectors, Funds for environmental protection and water management, and research institutes. Figure D.3 in Annex D provides an overview of key entities that play roles in air quality management in Poland.

Organizational Structure and Key Activities at the National Level

Poland has two high-level officials with air quality-related responsibilities: The Minister of Environment, and the Plenipotentiary of the Prime Minister, who is appointed by the Prime Minister. The Plenipotentiary is responsible for coordinating government activities to fully implement the recommendations of the “Clean Air” Programme (CAP) and chairs the National Air Quality Plan (NAQP) Steering Committee comprised of representatives of 13 sectoral Ministries. The Plenipotentiary is also responsible for cooperation with local government units and non-governmental organizations on air quality issues; review of all public funds and development of proposals to optimize public expenditures under the 2014-2020 budgetary forecasts; international cooperation with EU Member States, other countries and relevant international organizations; and fund raising from national and foreign sources for Clean Air Programme implementation.

None of the functions of the Plenipotentiary are part of any existing administrative unit of the Government, such as the Ministry of Environment, which is designated by the Environmental Protection Law to have responsibility for air quality management activities in Poland, including the setting of regulations. In addition, the Ministry is responsible for decision-making on the allocation of funds dedicated to environmental protection under the national budget, and coordination with Ministries of Energy, Health and Economy on aspects of air quality management and air pollution control that interface with the agenda of the respective Ministries. The Ministry also supervises the Chief Inspectorate of Environmental Protection, General Directorate for Environmental Protection, the National Fund for Environmental Protection and Water Management and research institutes, including the Institute of Environmental Protection-National Research Institute, National Centre for Emissions Management (KOBIZE) and the Institute for Ecology of Industrial Areas.

Coordination and Decentralization of Air Quality Management Responsibilities

At the sub-national level, several entities have air quality management responsibilities. At voivodeship-level they include: the Council, Marshal, Management Board, and Inspectorate of Environmental Protection. At the county (Powiat)- and municipality (Gmina)- levels, relevant actors include the Powiat Council, Starost, Powiat Board and Gmina Council.

Many countries in the world have an apex environmental ministry that includes technical and action-oriented units to implement air pollution control policies and enforce related regulations (Sánchez-Triana et al.,2014). The apex ministry would coordinate across sub-national authorities responsible for AQM to ensure the uniform development and application of consistent protocols, techniques, procedures and methodologies.

The typical rationale for the decentralization of environmental management (air quality in this case) is that regional and local authorities are more familiar with the specifics of local problems and their causes and are best positioned to direct local air quality management activities. They might achieve better outcomes if given the ability to choose the most appropriate policies and instruments. However, in Poland, extensive decentralization has not been fully effective. Among the reasons for this are differing capacities across the Voivodeships to carry out the analytical work that goes into air quality planning, and variable budgetary resources across regions. There is lack of mandatory uniform guidance such as for development of emission inventories and conducting air dispersion/air quality modeling. The government, through KOBIZE, is working on strengthening emission inventories and streamlining methodologies for their preparation by the regions.

A strong apex Ministry could ensure that technical capabilities, quality and consistent technical guidance documents, human and financial resources and therefore air quality planning is of similar quality across the voivodeships of Poland. This would enable consistent implementation of laws and regulations across the country leading to cleaner air across all of Poland.

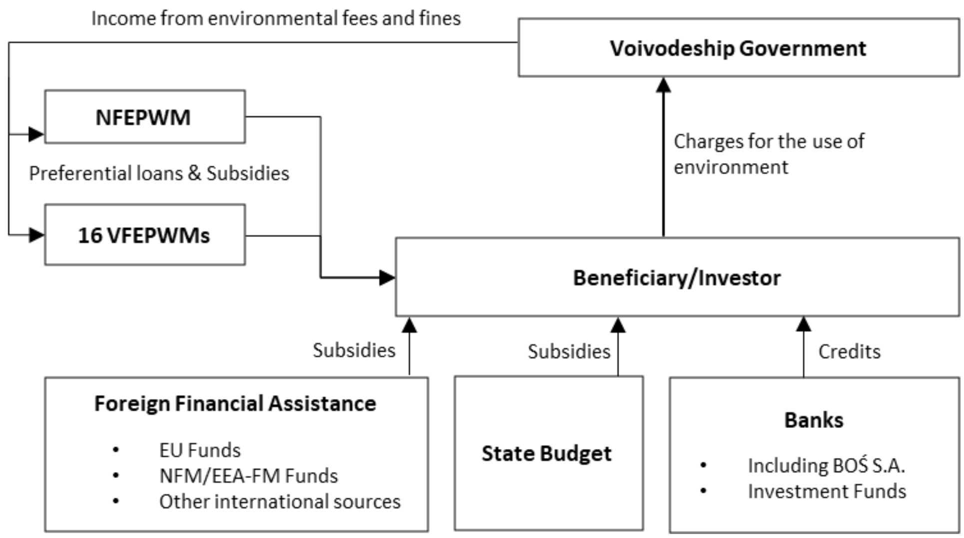
Some of the roles assigned to the Plenipotentiary for Clean Air could also be considered duties of the Environment Minister. Thus, the division of responsibilities between these two positions is not clear and poses a potential source of confusion about roles and diffusion of authority in the Polish system with respect to air quality management. It is not readily obvious when the Minister or the Plenipotentiary would have ultimate authority, and which one has the capacity to direct funds to solve specific air quality problems in Poland.

Funding for Air Quality Management

Funding of environmental protection in Poland is based on a system of funds (Figure 5.1). The National Fund for Environmental Protection and Water Management (NFEPWM) established in 1989 and 16 voivodeship funds for environmental protection (VFEPWMs) and water management, jointly referred to as environmental funds, provide the basis for the system. Generally, revenues from environmental charges and fines are collected by the environmental funds and earmarked for financing environmental projects through a variety of instruments including subsidies, preferential loans and bank credits. Additional funding sources in the system include: the EU and other international sources; Banks, notably Bank Ochrony

Środowiska S.A. (Bank for Environmental Protection); companies, local government and public entities; state and voivodeship budgets; and others (agencies, foundations, private sector). NFEPWM primarily supports implementation of strategic nationwide projects, while VFEPWMs support implementation of tasks of regional scope in the 16 voivodeships in Poland. From 1989 to 2012 the environmental funds provided co-financing in excess of PLN 62 billion for environmental protection, with slightly more than half of this total from the NFEPWM.

Figure 5.1. System of Financing Environmental Protection in Poland



Source: National Fund for Environmental Protection and Water Management, 2018[41]

The current level of financing of environmental protection from NFEPWM is approximately – EUR 1.2-1.4 billion annually, for various programmatic activities or funding categories for environmental protection (Kujda, 2018)[42]. The most closely related funding categories to AQM are: (i) climate and air protection, which includes energy efficiency, renewable energy sources, CO_2 reduction and climate change adaptation; and (ii) environmental monitoring.[43] To date, NFEPWM has financed 3,913 projects in the climate and air protection category, that have led to reductions of SO_2 (800,000 tons/year), dust (260,000 tons/year) and CO_2 (14.8 million tons/year); energy production from renewable energy sources (2.1TWh/year); energy savings from improved energy efficiency (3.4TWh/year); and completion of thermo-modernization of 4,228 public buildings. The new Clean Air Priority Programme with a budget of PLN 103 billion, will support emission reduction in the residential heating sector.

[41] Available at: http://www.nfosigw.gov.pl/
[42] PowerPoint presentation on the NFEP&WM delivered by K. Kujda, dated 30 August 2018, Warsaw
[43] Other categories include water protection and management, waste management and recycling, nature protection, prevention of environmental threats, environmental education, mining and geology, and scientific research.

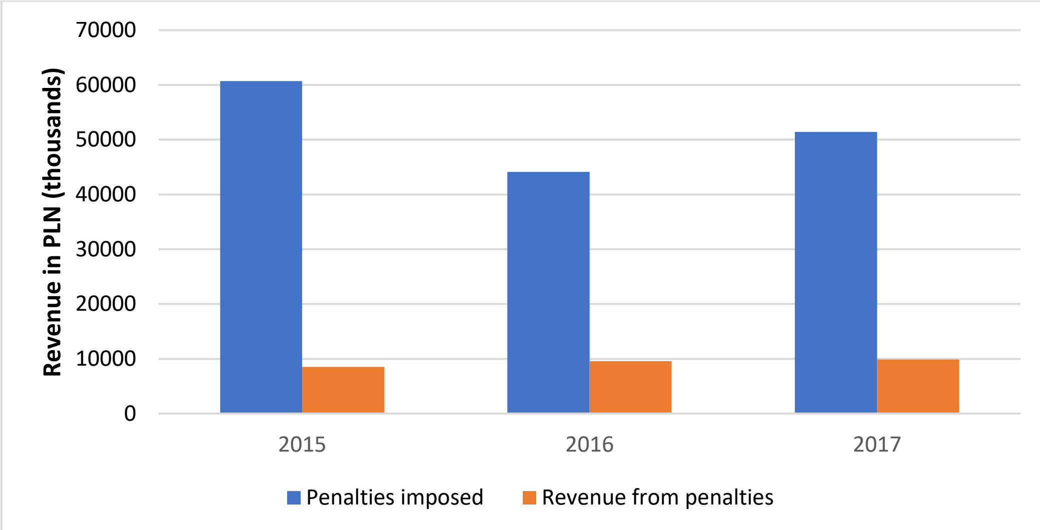
Total expenditures on fixed assets for environmental protection in Poland in 2015 amounted to PLN 15.2 billion (equivalent to 0.84% of GDP in 2015), of which PLN 4.3 billion was for protection of air and climate (LDB, 2018). By comparison, combined expenditures on sewage management and water protection (PLN 6.6 billion), and waste management (PLN 3.1 billion), amounted to PLN 9.7 billion i.e., more than double the expenditures on protection of air and climate. Although total expenditures significantly decreased in 2016 (PLN 6.5 billion) and 2017 (PLN 6.8 billion), expenditures for protection of air and climate were lower than for the other two categories combined. The amount dedicated to environmental expenditures in the national budget in 2018 amounted to PLN 411.6 million (including EU funds). There is no separate budget section dedicated to AQM.

At the regional and municipal levels, several innovative initiatives, involving diverse actors such as utility companies (district heating, power distribution, gas, combined heat and power) and equipment suppliers, have also been used for co-funding air quality improvement programs. In 2012 the municipality of Kraków signed a Cooperation Agreement with utility companies and energy suppliers, whereby each party declared a financial and technical contribution to the low-stack emission program for the city. The purpose was to provide funding to extend district heating and otherwise replace older coal-burning furnaces. Some exemptions to payment of environmental fees were granted so that the funds could be used for emission reduction activities (MPEC, 2015).

Economic instruments for environmental management

Poland collects fees based on emission registries, and administrative fines as penalties for exceeding permit emission limits. Payments are made by businesses and institutions which emit various pollutants, from both stationary and mobile sources. However, the residential sector is the leading contributor to PM emissions. If fee-paying sources of pollution decline, then revenues to assist with pollution from households, which is more serious, could also decline. Although in principle fees are based on the polluter pays principle, determining the effectiveness of fees in reducing pollution from the sectors and facilities that are paying the fees was beyond the scope of this study. The system of fees requires regular and accurate inspections of emission sources by the applicable Inspectorates of Environmental Protection as well as complete and accurate pollution registries, which are required for calculation of fees. Of all environmental categories, air and climate protection generated the highest annual revenue from fees between 2015 and 2017. In the same period, revenues from environmental penalties amounted to only 12-18% of penalties imposed pointing to the need to strengthen revenue collection from penalties (Figure 5.2).

Figure 5.2. Environmental Penalties Imposed and Revenue from Penalties



Source: Estimated by authors based on data from Poland Local Data Bank[44]

Air Quality Planning

Monitoring of Ambient Air Quality

Poland established the State Environmental Monitoring (SEM) in 1991 to provide reliable data on the state of the environment. The development of air quality zones for air quality assessments is required by the Environmental Protection Law.[45] Within each of the country's 46 air quality zones, air quality must be monitored to determine compliance with Limit Values and identify areas where air quality improvements are needed.

A notable achievement of the SEM has been the establishment of a comprehensive air quality monitoring network in the country, comprised of 310 stations (**Error! Reference source not found.** in Annex D). The Chief Inspectorate of Environmental Protection (CIEP), together with the Voivodeship Inspectorates of Environmental Protection (VEIPs), are responsible for air quality monitoring as part of the State Environmental Monitoring program. The CIEP is also responsible for ensuring quality assurance and quality control related to air quality monitoring, a function conducted by the National Reference Laboratory. Monitoring of particulate matter is focused primarily on gravimetric measurements and there is less coverage of monitoring of chemical species or constituents of particulate matter that are associated with combustion

[44] Available at https://bdl.stat.gov.pl/BDL/start

[45] Air quality zones are defined based on population: (i) zones with a population of more than 250,000; (ii) zones of cities with a population of over 100,000; and (iii) zones not belonging to cities with population of over 100,000.

sources. Incorporating such monitoring could be useful in better understanding the health impacts of air pollution in Poland, given the heavily coal-based economy. In addition, monitoring activities could include pollutants such as black carbon, a component of particulate matter, which has adverse health impacts and climate warming properties.

Public Disclosure of Air Quality Information

Real-time information on air quality throughout the country is provided through a portal operated by CIEP[46] as well as on the websites of respective VEIPs. The CIEP site also displays hourly updated air quality maps, provides air quality forecasts (for ozone) and maintains historical air quality measurements and annual air quality assessments. Seven VIEPs also provide air quality forecasts.

Polish Air Quality Index

The Polish Air Quality Index (PAQI) is intended to show the public how clean or dirty ambient air is. PAQIs are available for 7 pollutants: PM_{10}, $PM_{2.5}$, NO_2, SO_2, O_3, benzene and carbon monoxide. The PAQI and the European Air Quality Index (EAQI) for PM_{10} and $PM_{2.5}$ are presented in Table D.4 in Annex D. In air quality indices across the world, greener colors indicate good air quality, while red and dark red colors indicate poor air quality. However, the PAQI is less stringent than the EAQI. A PM_{10} reading of 61 µg/m^3 under the PAQI is considered to be “moderate” whereas it would be “poor” under the EAQI. Furthermore, a concentration of PM_{10} of 101 µg/m^3 (twice the daily Limit Value) is classified as “Sufficient” under the PAQI but would be “Very Poor” under the EAQI. In the same context, a $PM_{2.5}$ reading of 37 µg/m^3 is considered to be “moderate” under the PAQI, but under the EAQI would be “poor.”

The PAQI underestimates the real risk of harm and may give the wrong impression to the public, especially those who are not well informed about air pollution and its impacts on their health, as they usually pay attention to the colors and not to the values of ambient concentrations. To enhance the utility of the PAQI in promoting public awareness on air pollution and enabling people to take precautionary measures, the Limit Values of the respective air pollutants could be provided together with PAQI values and recommendations for sensitive groups.

46 http://powietrze.gios.gov.pl

High concentrations of pollutants can also trigger specific alerts. An *information threshold* is a concentration level above which there is a risk to human health from brief exposure for particularly sensitive sections of the population (e.g. people with asthma or chronic obstructive pulmonary diseases, young children and the elderly) and for which immediate and appropriate information is necessary. An *alert threshold* is a concentration level above 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 an EU Member State. The concentrations required to trigger the *information threshold* and *alert threshold* for PM_{10} are 200 µg/m^3 and 300 µg/m^3 respectively. The Polish alert threshold for PM_{10} (300 µg/m3) is the highest amongst EU Member States. As $PM_{2.5}$ is now the foundation of air pollution health risk assessment, alerts should eventually be based on these concentrations.

Air Quality Planning at the Sub-National Level

Air quality planning actions need to be taken locally where the presence and impacts of air pollution directly affect people. The Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe Air (CAFÉ Directive) requires Member States to prepare local air quality plans (AQPs) for zones or agglomerations where ambient air limit values are exceeded. In addition to AQPs, additional air quality planning instruments for use at the local level in Poland, include Short-Term Action Plans (STAPs) and Anti-Smog Resolutions (ASRs).

Annex XV of the CAFÉ Directive provides a framework for the information to be included in AQPs for improvement in ambient air quality. The Environmental Protection Law is the main Polish law that transposes the CAFÉ Directive and makes provision for the development of AQPs, STAPs and ASRs. The Regulation on air quality plans and short-term action plans (JoL 2012, item 1028) provides the scope of issues to be covered by AQPs. The ASRs were introduced through the so-called Anti-Smog Act of 2015, which amended the Environmental Protection Law. There is no specific regulation that relates to the scope of ASRs.

Air Quality Plans - An AQP is developed for each pollutant whose level exceeds the Limit Value although joint AQPs may be prepared when there are exceedances for multiple pollutants in a zone or several zones. AQPs are adopted via resolution of the voivodeship council (*Sejmik*) (**Error! Reference source not found.** in Annex D). There are currently AQPs in each of the 46 zones, covering pollutants such as PM_{10}, $PM_{2.5}$, B(a)P, NO_2, ozone, arsenic, CO and benzene. Majority of the zones focus their AQPs on three pollutants: B(a)P – 46 zones, PM_{10} – 42 zones, and $PM_{2.5}$ – 27 zones (Table D.5 in Annex D).

Short-Term Action Plans – STAPs consist of short-term actions aimed at reducing the risk of exceeding normative values for limit values, target values or alert thresholds. A STAP may be elaborated separately or as part of an AQP and is adopted via resolution of the voivodeship council (*Sejmik*).

Anti-Smog Resolutions – Unlike AQPs, which may address various sectors, ASRs are aimed solely at reducing negative impacts of air pollution from the residential sector. ASRs can be voluntarily adopted by voivodeships via resolution of the voivodeship council. The earliest ASR was adopted in Kraków Agglomeration in October of 2016, and there are currently 13 ASRs in force in 8 of 16 voivodeships where about 65% of Poland's population lives. ASRs include restrictions on use of certain types of fuel combustion installations and/or certain types of solid fuels. ASRs also include bans of the use of low-quality solid fuels, coal mud, flotation residues, lignite and biomass with moisture content higher than 20%, depending on voivodeship. Complete ban of the use of solid fuels will become effective in Krakow in September of 2019, and in Dolnośląskie voivodeship in July of 2028.

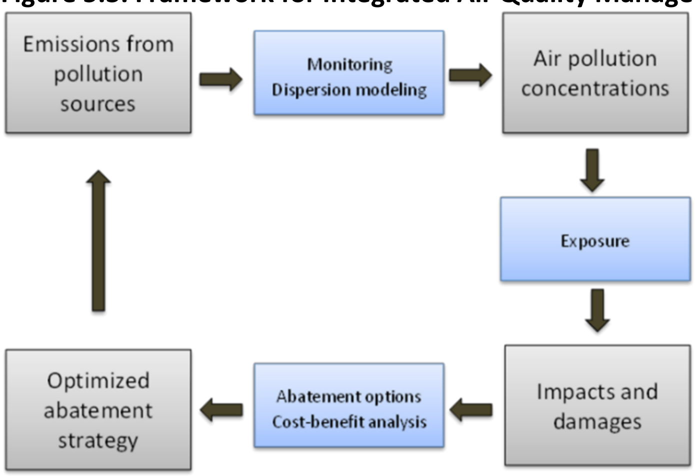
Benchmarking Selected AQPs Against Integrated Air Quality Management (IAQM) Planning

In addition to the Regulation on air quality plans and short-term action plans (JoL 2012, item 1028), which provides a broad set of requirements for the scope and content of AQPs, additional guidance materials commissioned by the Ministry of Environment address: (i) basic methods for emission inventory preparation; (ii) methodological aspects of mathematical modeling for AQM; and (iii) regulatory aspects and preparation of AQPs (KCIE, 2003; Łobocki, 2003 and Ośródka, 2008). These guidance materials are voluntary and have not been updated since their development to reflect up to date experience gained by national and regional authorities in AQM (KCIE, 2003; Łobocki, 2003 and Ośródka, 2008). Other documents targeted at public administrative entities provide expert opinions for improving AQM (ATMOTERM, 2014; ATMOTERM, 2017). The dearth of uniform, mandatory guidance could result in heterogeneity and inconsistency in quality of AQP design across different voivodeships and thus undermine the effectiveness of AQPs particularly where technical and budgetary resources are constrained.

An Integrated Air Quality Management (IAQM) approach provides a comprehensive planning framework for reducing air pollution through economically effective interventions (Figure 5.3). IAQM involves four key steps: (i) understanding air pollution sources, which involves identification of emission sources, by conducting a detailed inventory, including stationary and non-stationary sources; (ii) understanding air quality through a combination of air quality monitoring data and atmospheric dispersion modeling to determine air pollution concentrations and their distribution; (iii) understanding health impacts by translating observed and/or modeled air pollution concentrations into impacts by estimating population exposure and then applying dose-response functions to link pollution levels to health outcomes, specifically morbidity and premature mortality; and (iv) optimizing abatement strategy on the most economically effective interventions, by comparison of emission control costs with benefits i.e., reduced health damage costs.

In Poland some parts of the IAQM approach work better than others. The following paragraphs examine how AQP in Poland compares with the IAQM, based on review of selected AQPs - in mazowieckie voivodeship (Płock, Radom, Warsaw agglomeration, and mazowieckie voivodeship) and in małopolskie voivodeship – and existing guidance material, and identifies opportunities to enhance AQP development.

Figure 5.3. Framework for Integrated Air Quality Management Planning



Source: Awe et al., 2015

Understanding air pollution sources – Emission inventories are a major uncertain element of the IAQM framework in Poland, and thus pose a challenge to the effectiveness of air pollution abatement measures. A major drawback is that emission inventories are prepared in different ways and are not uniform in methods or accuracy across regions. AQPs contain insufficient information about the methodology used for development of emission inventories, notably for residential and transport sectors. Information on the traffic emission model and input data such as traffic volume, emission factors, vehicle fleet is sparse or lacking. In the residential sector, information on input data for emissions calculation and emissions factors is not robust. Furthermore, AQPs do not specify how supra-regional background air pollution is addressed. Incomplete data on pollution sources leads to underestimation of polluting emissions, thus undermining the ability of AQPs to achieve air quality improvements. It is envisaged that the ongoing development of a nation-wide, unified emissions inventory being undertaken by KOBIZE will provide data for each voivodeship. To enhance and sustain the effectiveness of this important undertaking by the government, it would be important to conduct regular inventory updates using unified methodologies at the regional level. In addition, existing guidance material for inventory development at the regional level can be strengthened by incorporating (i) uniform emission factors for similar sources; (ii) methods for reliable assessment of amounts and structure of fuels used, types and numbers of individual heating installations; (iii) methods for emission inventory verification and evaluation of based on comparison of modeling results with observations and source apportionment analysis; (iv) uncertainty analysis to assess inventory accuracy; and (v) provisions for incorporating regional and transboundary pollution in air quality modeling. Furthermore, the Regulation on air quality plans and short-term action plans could be updated to enforce consistent methodology for gathering emissions data and estimating emissions, and mandatory application of such methodology.

Understanding air quality – The air quality monitoring network in Poland is extensive and should be considered a strong element of the IAQM framework. Collected data are easily accessible, both in raw form and in the form of annual air quality assessments. All AQPs reviewed applied CALPUFF atmospheric dispersion modeling for base and target years. However, descriptions of source of meteorological, topographical or land use input data, evaluation of modeling results for the modelled area and model uncertainty are not always clearly provided thus limiting the ability to compare modeled results with actual observations. Existing AQP guidance does not address source apportionment. The structure of the CALPUFF model allows for dispersion modeling from point, linear and area sources, which can subsequently be used to identify key sources responsible for exceedances. However, results obtained using this approach depend on the quality of emission inventories, which is uncertain. In the case of the AQP for małopolskie voivodeship, modeling was also used to compare the effectiveness of alternative emission reduction scenarios.

To better understand the influence of pollution sources on air quality, existing guidance could be strengthened to include measurement of species and constituents of particulate matter, such as elemental carbon, organic carbon, sulfates, nitrates, ammonium, heavy metals and black carbon. In addition, guidelines are needed that allow for application of unified modeling principles for diagnostic and prognostic model runs including how to: (i) deal with inflow of pollutants; (ii) incorporate meteorological conditions; (iii) perform evaluation of modeling results; and (iv) calibrate models and adjust them to monitored observations. The Regulation on air quality plans and short-term action plans could be updated to ensure that source apportionment, notably for $PM_{2.5}$, is conducted as part of AQP development, together with analysis of spatial and temporal variability of pollutants from various sources and linkages to meteorological conditions.

Understanding health impacts – Inclusion of health impact assessment in AQPs is not required. Observed and/or modeled air pollution concentrations are not translated to health impacts using concentration-response functions that link pollution to health outcomes. As a result, AQPs are missing one of the key pillars of IAQM. From a legal perspective, AQPs are intended to be tools for ensuring that the Limit Values of air pollutants are not exceeded. However, the main purpose of air quality standards is to protect human health. The lack of reference to health impacts is therefore an important drawback of AQP design. The Regulation on air quality plans and short-term action plans (JoL 2012, item 1028) could be updated to ensure that health impact assessment is obligatory in AQPs. Furthermore, guidance on approaches and methods to be used for health impact assessments in AQPs could be developed by Environment and Health Ministries and other stakeholders, including the National Institute of Public Health – National Institute of Hygiene, as appropriate.

Optimizing abatement strategy – The optimization of abatement strategies based on identification of the most economically effective abatement interventions is not routinely included in AQPs. Cost-benefit analysis estimates cost and benefits (reduced health damage) of interventions. The current Polish guidance indicates that the total costs of abatement measures should be estimated in AQPs, but more specific guidance for undertaking in-depth economic analysis is not provided. At the same time, the guidance underscores the need for remedial measures to be negotiated and agreed to by all stakeholders in a given zone. A possible consequence could be that measures for which consent is easiest to achieve are more likely to be included in AQPs than the most economically effective measures. Some voivodeships, such as małopolskie have used cost-effectiveness analysis, which estimates the cost per unit mass of pollutant reduced, to compare alternative remedial measures. Cost-benefit analysis, however, provides a basis for prioritizing alternative interventions that is anchored to health outcomes, and can help decision-makers to efficiently allocate funding for improving air quality. Prioritization of interventions based on cost-benefit analysis could be a useful tool for regional and local authorities that are often faced with making decisions on allocation of limited financial resources between multiple competing needs. The Regulation on air quality plans and short-term action plans (JoL 2012, item 1028) could be updated to include the requirement for abatement strategy optimization in AQPs to ensure effective allocation of financial resources to improving air quality in a given zone.

Implementation of AQPs and ASRs

AQPs have been implemented in Poland for several years but air pollution continues to be a challenge. Ośródka (2008) identified shortcomings of air quality planning and implementation in Poland and suggested areas for improvement, including among others: (i) stronger focus on quantitative rather than qualitative data in AQPs; (ii) cooperation between neighboring voivodeships on supra-regional air pollution; (iii) appointment of AQP steering committees at voivodeship level to supervise AQP development and implementation, including representatives of voivodeships and gminas administrations, voivodeship inspectorates of environmental protection, local industries, road and public transport authorities, energy and heating plants and environmental protection experts); and (iv) monitoring and reporting of AQP implementation by AQP steering committee. Some additional aspects related to implementation of AQPs in Poland are discussed below.

AQPs are adopted as local laws in Poland. Consequently, they can specify broad information about the type and scope of actions or measures that can be taken within a zone but cannot specify actions or measures that directly impact the implementation of such measures. For example, while an AQP can indicate boiler replacements as one of the actions to be taken in a zone, it cannot indicate the number of boilers to be replaced or in which specific gminas replacements should be conducted. Such detail is usually provided in Low Emission Abatement Programs (LEAPs), Gmina Low Emission Programs (GLEPs) undertaken by gminas at the local level. Furthermore, the Marshal of the voivodeship, who has responsibility for implementing actions in the AQP, does not have legal tools to enforce execution of specific actions by gminas. Gmina-level programs and tools could potentially reinforce AQP implementation. In order to enhance the implementation effectiveness of AQPs, which typically cover multiple gminas, mechanisms and incentives could be introduced to ensure that gmina-level actions and programs are well articulated and consistent with AQPs, including accountabilities for air quality outcomes.

Multiple AQPs may be adopted within a single voivodeship or even within a single zone. For example, there are two AQPs for Warsaw – one for PM_{10} and NO_2, and another for $PM_{2.5}$. A similar situation also exists in some other cities and zones in other voivodeships. In voivodeships such as małopolskie, a single AQP has been adopted for the entire voivodeship. This diversity of approaches to air quality planning across voivodeships, potentially provides an opportunity for taking stock of implementation experience from the different approaches, drawing lessons learned and exchanging knowledge between voivodeships in order to enhance effectiveness of AQPs in improving air quality outcomes. An apex institution (e.g. the Ministry of Environment) could play a coordinating role in this regard.

Adequate funding is an important factor in ensuring effectiveness of implementing air quality planning. Understanding criteria for prioritizing activities to be funded and ensuring that environmental expenditures are aligned with air quality planning priorities are important for enhancing implementation effectiveness of AQPs. In some countries, public environmental expenditure reviews have been used in informing priority setting for air quality management and could be a valuable tool at the regional level, particularly in the voivodeships where the cost of ambient air pollution is highest.

AQPs are 10-year plans, which the Voivodeship Management Boards are responsible for preparing. In practice AQP preparation is often outsourced to commercial contractors through a bidding process. The draft AQP is provided to administrative stakeholders including the starost and mayors of gminas and towns, and presidents of cities as applicable. These stakeholders have the opportunity to provide comments on the draft AQP during a limited time period (about 1 month) after which the AQP is adopted via resolution of the voivodeship council (*Sejmik*). If AQP implementation does not result in bringing air quality into compliance with air quality standards, the Voivodeship Management Board is obliged to develop an AQP update within 3 years of the date of adoption of the existing AQP. To enhance implementation effectiveness of AQPs, some considerations are: (i) where AQP preparation is outsourced, technical criteria are appropriately taken into account in evaluating and selecting bids, in addition to cost; (ii) experts in air quality management are included during the preparation and review stages of the AQP and of any AQP updates to provide guidance on adequacy of proposed measures and implementation arrangements to achieve the needed air quality improvements; and (iii) inclusion of relevant performance indicators in AQPs.

ASRs represent an important tool for reinforcing the implementation effectiveness of AQPs. Adoption and implementation of ASRs could be expanded across the country. Given the focus of ASRs on residences, a strong public awareness component is needed to ensure that citizens and households are aware of their obligations to comply with ASR requirements. Efforts to raise public awareness vary across different voivodeships. Małopolskie voivodeship is a notable example where Ecoadvisors are employed by gminas to inform and educate the public on requirements of ASRs.

Summary

Poland has taken important steps under its Clean Air Programme (CAP), including adoption of regulations on technical requirements for small scale solid fuel boilers, and solid fuel quality, and enactment of a law on electromobility and alternative fuels. Ensuring enforcement of the provisions of these laws will be crucial next steps for the Poland in effectively tackling air pollution. Continued measures to make fuel quality standards more stringent in the short to medium term especially with respect to coal quality standards for households and other small consumers will also be important. Efforts to promote electromobility should also take into account distributional impacts as people of lower economic status are more likely to own more polluting vehicles.

There are two high level officials with air quality-related responsibilities at the national level, namely the Minister of Environment and the Plenipotentiary of the Prime Minister. Consolidating and clarifying roles and responsibilities for air quality management at the national level would help to avoid potential inefficiencies associated with duplication and overlaps of roles. In addition, given the complex and decentralized institutional framework for air quality management, a coordinated, central institutional approach is needed to bring consistency to addressing air quality management in Poland.

A strong element of the IAQM approach in Poland is the extensive air quality monitoring network throughout the Poland. Monitoring of the more health-damaging $PM_{2.5}$ is a more recent development than measurement of PM_{10}. Continued monitoring of $PM_{2.5}$ should be expanded and monitoring systems can be strengthened by incorporating measurement of ultrafine particulate matter, notably black carbon. Monitoring of chemical species and constituents of particulate matter (PM) that are associated with combustion processes could be undertaken given the heavy use of coal in Poland and to better understand the long- and short-term health effects of PM species and constituents on the Polish population.

Although air quality is publicly disseminated online in real-time, a transition to a more health-based approach to the Polish Air Quality Index (PAQI) is needed. The existing PAQI underestimates the health risks of air pollution to the public, which can be misleading in terms of the air quality status and for informing protective or precautionary behavior by members of the public. Furthermore, given the adverse impacts of $PM_{2.5}$ in health outcomes, air quality alerts should eventually be based on $PM_{2.5}$.

Air Quality Plans (AQPs) developed by voivodeships vary in their treatment of aspects of air quality planning. A strengthened approach to Integrated Air Quality Management (IAQM) is needed, which incorporates essential aspects including: (i) development of comprehensive and accurate inventories, notably for residential and transport sectors; (ii) air dispersion models; (iii) supra-regional and transboundary pollution; (iv) source apportionment analysis; (v) health impact analysis; and (vi) cost-benefit analysis. It will be important to ensure that existing guidance material is up-to-date, and that new guidance material is developed on aspects of

IAQM not currently included in existing guidance. Furthermore, mechanisms can be put in place to ensure that application of such guidance is mandatory, for example through updates to the Regulation on air quality plans and short-term action plans (JoL 2012, item 1028).

Some of the ways in which the design and implementation effectiveness of AQPs could be improved include: (i) greater focus of AQPs on quantitative data; (ii) inclusion of performance indicators in AQPs; (iii) incorporation of persons with technical and professional expertise in air quality management in review processes for preparation and implementation of AQPs and AQP updates; (iii) putting in place mechanisms and incentives to ensure that gmina-level actions and programs (e.g. LEAPs) are well articulated and consistent with AQPs; (iv) clarification of accountabilities for air quality outcomes in AQPs.

The differences in approaches to air quality planning across voivodeships provides an opportunity for stock-taking of regional experiences. Experiences from around the world indicate that an apex organization (e.g. Ministry of Environment) could take a central coordinating role in facilitating stock-taking, identifying lessons learned and promoting knowledge exchange across regions as part of efforts to ensure consistency of approaches.

Anti-smog resolutions (ASRs) provide a tool for implementing actions envisaged in AQPs or in Low Emission Abatement Programs developed by gminas. ASRs are currently adopted in about half of Poland’s voivodeships, and their wider adoption throughout the country should be encouraged and supported through appropriate financial mechanisms and strengthened public education and awareness on the provisions of ASRs.

Adequate funding is an important factor in ensuring effectiveness of implementing air quality planning and management. Understanding criteria for prioritizing activities to be funded and ensuring that environmental expenditures are aligned with air quality planning priorities are important for enhancing implementation effectiveness of AQPs. In some countries, public environmental expenditure reviews have been used in informing priority setting for air quality management and could be a valuable tool at the regional level, particularly in the voivodeships where the cost of health damage from ambient air pollution is highest.

Poland collects fees based on emission registries, and administrative fines as penalties for exceeding permit emission limits. Payments are made by businesses and institutions which emit various pollutants, from both stationary and mobile sources. However, the residential sector is the leading contributor to PM emissions. Although in principle fees are based on the polluter pays principle, determining the effectiveness of fees in reducing pollution from fee payers merits further study. Of all environmental categories, air and climate protection generated the highest annual revenue from fees between 2015 and 2017. However, in the same period, revenues from environmental penalties amounted to only 12-18% of penalties imposed pointing to the need to strengthen revenue collection from penalties.

Chapter 6. Conclusions and Recommendations

Ambient Air Quality in Poland

Despite significant efforts to reduce polluting air emissions, during and after the economic transition in the 1990s, Poland remains home to many of the most polluted cities in the European Union (EU).

Many people in Poland are exposed to levels of ambient air pollution, notably particulate matter ($PM_{2.5}$), that are harmful to health. $PM_{2.5}$ is the cause of disease and death associated with lung cancer, chronic obstructive pulmonary disease, ischemic heart disease, stroke, respiratory illness. Annual average ambient concentrations of fine particulate matter, $PM_{2.5}$, concentrations are often multiple times the maximum levels allowed under EU law (25 $\mu g/m^3$) and the WHO air quality guideline value (10 $\mu g/m^3$). The most widespread exceedances of EU air quality Limit Values are seen in south and southwestern Poland.

At the base of Poland's air quality challenges is the country's heavy dependence on coal as a source of fuel. Significant amounts of coal are used in residential and commercial heating, and in industry and power production. The residential and industrial sectors account for the largest shares of energy consumption at 29% and 29.9% respectively, followed by the transport (24%) and commercial (17.2%) sectors (IEA, 2017). There has been a significant reduction in the total quantity of coal used since socialist times, and notable increases in the use of natural gas and renewable energy sources. However, coal, which is generally a more highly polluting energy source, is still dominant. It is projected that by 2020, Poland will account for about 50% of hard coal use by small consumers in Europe.[47]

The significant health and economic impacts of ambient air pollution call for a paradigm shift. In particular, dedicated efforts are needed to shift from a heavy reliance on coal to a more sustainable growth path that reduces environmental and health impacts of coal reliance, including through shift to use of cleaner fuels in households, industry and power generation, and curbing transport emissions.

The residential sector is the most important source of ambient $PM_{2.5}$ pollution in most areas in Poland although existing national inventories likely underestimate emissions from the

[47] Price-Induced Market Equilibrium System (PRIMES) Reference 2016 scenario. PRIMES is an EU energy system model.

sector. Burning of polluting solid fuels such as coal, coal wastes, biomass and wastes for heating purposes in small boilers and individual stoves in households is the main source of ambient $PM_{2.5}$ pollution. The residential sector is also the leading source of Benzo[a]pyrene, a known carcinogen. The contribution of the residential sector to ambient air pollution is most evident during winter months i.e., peak heating season. Notwithstanding the important role of the sector, existing national emissions inventories suffer systemic uncertainties related to real-life emissions; activity statistics, specifically information gaps about use of coal wastes (i.e., coal muds and flotation residue) and non-commercial biomass use in stoves and boilers; and burning of waste materials in residential heating installations. Additional important contributors to ambient particulate matter pollution are industry, energy and road transport. The energy sector continues to be an important source of SO_2 and NO_x, and transport a source of NO_x, although SO_2 and NO_x are not widespread problems across the country.

While most attention to date has focused on the residential sector, the contributions to AAP, of additional sources such as transport and transboundary sources, need to be better understood and quantified. During warmer months of the year contributions from other sources such as transport could become more prominent. Poland's car fleet is the oldest and sixth largest in the EU and continues to grow. Older cars without adequate emission controls could be important contributors of air pollution, particularly in cities or areas with high density of transport networks. However, uncertainties relating to emissions contributions, particularly related to actual mileage and environmental performance of used imported vehicles, need to be addressed. In addition, in parts of southern Poland, transboundary sources contribute a significant share of AAP, reaching more than 60% in śląskie voivodeship (SAO, 2018). In order to better assess and target domestic AAP mitigation measures, increased collaborative approaches at the regional level may be called for to complement domestic measures and enhance air quality outcomes.

Health Burden and Economic Cost of Ambient Air Pollution in Poland

Exposure to ambient $PM_{2.5}$ imposes an enormous health burden and productivity losses on the Polish population. This report estimates that AAP is associated with 23% of the annual burden of bronchitis in children and 33% of the annual burden of chronic bronchitis in adults. The highest burden is in mazowieckie and śląskie voivodeships. AAP resulted in 213,313 cases of bronchitis in children, 49,061 cases of chronic bronchitis in adults, 19,139 hospital admissions for respiratory illness and 16,847 lost days of work. It is also associated with 2% of the cardiovascular and 4.5% of respiratory hospital admissions and 8% of the total lost workdays. The morbidity burden is highest in wielkopolskie, mazowieckie, śląskie, łódzkie, and małopolskie voivodeships. The overall morbidity burden is accentuated during winter months when pollution levels are elevated due to increased residential heating, and spikes occur in cardiovascular and respiratory hospital admissions and respiratory infections. The daily burden of morbidity attributable to short-term air pollution is at least 1.6-2 times higher in winter months than in other seasons.

This report conservatively estimates that 25,280 premature deaths are caused by ambient $PM_{2.5}$ pollution in Poland in 2016. Following the Global Burden of Disease (GBD) 2016 methodology, this conservative approach calculates premature, age specific mortality from five diseases - lung cancer, ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), and lower respiratory illness – that are directly linked to $PM_{2.5}$ pollution. By contrast, the recent EEA 2018 estimate of 44,500 deaths, is for all-cause or non-accidental mortality (i.e., all deaths excluding poisoning, suicide and war), and assumes a linear relationship between mortality and $PM_{2.5}$ concentration for population above age 30.[48]

On average, premature deaths attributed to ambient air pollution (AAP) account for approximately 6.4% of total mortality in Poland in 2016 and mortality rates are highest in voivodeships in southern Poland. The rate of mortality attributed to ambient air pollution is estimated at 66 per 100,000 on average in Poland. However, this number increases to 71-82 per 100,000 in voivodeships in the south and southwest of Poland, notably dolnośląskie, łódzkie, małopolskie, śląskie, and świętokrzyskie. The number of deaths attributed to ambient air pollution is highest in śląskie, mazowieckie, małopolskie, and wielkopolskie voivodeships. Prioritizing interventions to reduce AAP in these voivodeships will have the most significant impact in reducing the substantial health burden.

The economic cost associated with disease and premature death from exposure to ambient $PM_{2.5}$ is estimated at US$31- 40 billion, equivalent to 6.4-8.3% of GDP in 2016, using the welfare-based approach and US$3 billion, equivalent to 0.6% of GDP in 2016, using foregone output-based approach. The total cost of morbidity is estimated at about US$1.05 billion and working adults carry the largest share or 75% of this cost, related to lost work days due to illness. Based on forgone output, morbidity accounts for about 40% of the total cost of health damages. The total cost of health damage from ambient air pollution is highest in mazowieckie and śląskie voivodeships. The welfare-based cost exceeds total current expenditures on health care (both public and private) in 2015 (US$30 billion) in Poland. The total annual budget of the National Health Fund, the publicly funded healthcare system in Poland, is about US$18 billion in

[48] For comparative purposes, this report also estimates that 44,811 deaths are caused by AAP, applying the methodology used in EEA (2018). The estimates from both sources are very close.

2016. On a per capita basis, the voivodeships in the south and southwest of Poland bear the most significant annual cost, with śląskie and dolnośląskie bearing cost in the range of US$1100-1200/person if a national value of statistical life (VSL) is used for mortality valuation. The costs could increase up to US$1200-1300/person, in śląskie voivodeship, when calculated based on the individual VSL of each voivodeship.

Future Emission and Air Pollution Scenarios

Full implementation of the requirements of adopted and planned national and regional/voivode legislation (NRAQP scenario) will bring substantial air quality and health benefits. The development of $PM_{2.5}$ emissions into the future is affected by the legislative environment, in the case of Poland being EU regulations and national air quality legislation. With a primary focus on the residential sector, this report used the GAINS model to simulate impacts of different scenarios of EU, and existing and recently adopted national legislation in Poland, on emissions of $PM_{2.5}$ (and $PM_{2.5}$ precursors). The results showed that ambitious and early actions targeting solid fuel heating installations in the residential sector, through implementing requirements of existing and planned national and regional legislations, including the National Air Quality Plan, Clean Air Programme, standards for fuel boilers, national fuel quality standards and regional Anti-smog requirements (e.g. expedited implementation of Class 5 or Eco-design boilers and scrapping of existing boilers that are non-compliant with Eco-design), supported by financial mechanisms, will bring substantial reductions of primary $PM_{2.5}$ emissions especially in the south of Poland, thus significantly enlarging the areas of the country that comply with EU Limit Value and WHO air quality guideline value for $PM_{2.5}$.

However, in order to achieve compliance with Poland's emission reduction requirements under the National Emissions Ceiling Directive (NECD) and bring ambient air quality closer to the WHO $PM_{2.5}$ guideline value (10μg/m^3), further measures will be needed to address ammonia emissions from agriculture, an important source of secondary particulate matter pollution, and emissions from industry. Without additional actions to curb ammonia emissions, agriculture, the key source of ammonia emissions, will become an even more important contributor to the formation of ambient $PM_{2.5}$. The application of nitrogen-containing fertilizers in agriculture leads to the emission of ammonia, which combines with NO_x and SO_x from other sources such as power plants and traffic, to form secondary particulate matter pollution. The need for further reductions of $PM_{2.5}$ emissions from industry would depend on successful implementation of Polish national and regional air quality legislation scenario, and effective implementation could minimize the need for additional measures in industry. PM emissions control costs increase over time underscoring the need for timely action. Recent legislation on advanced Euro 6 standards is expected to deliver a significant decrease in emissions from mobile sources.

Although switching to new, high efficiency stoves and boilers will reduce coal consumption and thus CO_2 emissions from Polish households, this reduction will be limited. Expansion of cleaner energy sources such as gas and district heating could possibly provide higher CO_2 reductions. Given the significant amounts of coal used in the Polish residential sector, this report examined the potential for CO_2 mitigation from this sector using the GAINS model. It is estimated that the introduction of new stoves and boilers with higher efficiency will result in about 10% reduction of CO_2 emissions from coal combustion in this sector, which translates to about 5% reduction of total emissions from the residential sector or less than 1% reduction in the total national CO_2 emissions in 2030. Consequently, only limited CO_2 mitigation potential is estimated from coal combustion in Polish households when only switching to more efficient stoves and boilers is pursued. Higher reductions could possibly be achieved with further expansion of gas and district heating, but this would require analysis to be confirmed.

Interventions to Reduce Air Pollution from Different Sectors in the Voivodeships where Cost of AAP is Highest

Benefit-cost analysis provides an informed basis for prioritizing interventions to reduce air pollution from different sectors particularly in voivodeships where the mortality and morbidity costs of ambient air pollution are highest. Based on scenarios developed in this study with the GAINS model, results of voivode-level source apportionments conducted by the Polish Supreme Audit Office (SAO, 2018), a World Bank study on financial instruments for supporting energy efficiency in single family buildings (SFBs) in Poland (World Bank, 2018) and other sources, this report conducted benefit-cost analysis (BCA) of interventions to reduce air pollution from the residential sector, transport and point sources in four voivodeships: i.e., mazowieckie, małopolskie, śląskie and dolnośląskie where the costs per capita of ambient air pollution are highest in the country. The BCA allows a comparison of the health benefits of an intervention i.e., avoided cost of premature mortality and morbidity, and cost of implementation of the intervention. It should be noted that the range of interventions studied in this report are not exhaustive but instead demonstrate the usefulness of BCA for selecting and targeting interventions to reduce AAP beyond a single sector.

Interventions to replace old, polluting residential boilers are economically effective alone and when combined with full or partial retrofit of single family buildings in all four voivodeships. BCA showed that all interventions examined - replacement of old boilers with new ones;

replacement of boilers and partial thermal retrofit of SFBs; and replacement of boilers and full thermal retrofit of SFBs - are economically viable i.e., yield benefit-cost ratios (BCRs) greater than one. In all voivodeships, replacement of old boilers was more economically effective than the other two interventions. BCRs were highest in mazowieckie and małopolskie voivodeships indicating that interventions in these voivodeships should be prioritized. The analysis assumed a gradual shift to gas boilers and an increase of municipal heating connections.

BCA of transport sector interventions suggest that implementation of the government's electromobility plan is economically effective in urban centers in three of four voivodeships, and interventions should be prioritized in śląskie voivodeship. The three interventions analyzed included structural changes in the automobile fleet, specifically (i) replacement of a share (10%) of the oldest cars with new ones that meet at least Euro 5 standards; (ii) implementation of Poland's electromobility plan by 2025 with 1 million electric and hybrid vehicles registered; and (iii) implementation of (i) and (ii). Implementing the electromobility plan was found to be economically viable in all voivodeships except dolnośląskie, and most viable in śląskie voivodeship. The quantified benefits of electromobility did not include additional benefits such as strengthening of electricity transmission and distribution grids, job creation and boosts to GDP growth, which would call for further analysis within a general equilibrium framework.

The results of BCA to reduce pollution from point sources (high stacks) suggested prioritization of interventions in śląskie voivodeship. For point sources, a group of interventions to reduce pollution from high-stack point sources (power generation and industry) including in-furnace control-limestone injection, enforcement of low-sulfur coal (0.6% sulfur content) use, and wet flue gas desulfurization were analyzed. BCRs of unity or greater were achieved only in śląskie voivodeship. However, uncertainties related to how the transboundary nature and uniform character of emissions from high-stacks may affect the results need to be better understood.

Policy and Institutional Aspects of Air Quality Management in Poland

There is a need to consolidate and clarify roles and responsibilities for air quality management at the national level. Poland has two high level officials with air quality-related responsibilities at the national level: the Minister of Environment, and the Plenipotentiary of the Prime Minister, who is appointed by the Prime Minister and has the responsibility to coordinate government activities to implement the recommendations of Poland's Clean Air Programme. In addition, the Plenipotentiary is responsible for cooperation with local government units of different levels and non-governmental organizations, and international cooperation. None of these functions are part of any existing administrative unit of the government, such as the Ministry of Environment. Consolidating and clarifying roles and responsibilities for air quality management at the national level would help to avoid potential inefficiencies associated with duplication and overlaps of roles.

Poland has a complex and decentralized institutional framework for air quality management. However, a coordinated, central institutional approach is needed to bring consistency to addressing air quality management in Poland. Roles and responsibilities of entities involved in air quality management in Poland are divided between several representatives of national, regional and local governments. Decentralization does have its merits, notably that responsible government agencies can more readily respond to local environmental management problems. However, with the decentralized structure come challenges in ensuring uniformity of air quality management efforts and standards across levels of government, as well as variations in budgetary and technical resources and capacity. The effects of these challenges are most notably felt at the local level where exposure to ambient air pollution affects the day-to-day lives of citizens.

In Poland, variability in fundamental elements of air quality planning at the local level is symptomatic of the challenges of the decentralized governance structure for air quality management. Air Quality Plans (AQPs) are developed at the local level by the voivodeships and suffer some shortcomings, which pose constraints to their effectiveness: they vary across voivodeships in their treatment of different elements of air quality planning; and needed technical guidance to strengthen the effectiveness of their design is lacking, out of date or not mandatory. The robustness of AQPs mirrors variations in the level of funding and technical capacity across regions. Some AQPs tend to have more of a diagnostic rather than prescriptive focus, and do not have adequate information to implement an integrated air quality management approach. Strengthening the Ministry of Environment to play a central role, which has an overall coordinating role and sufficient technical expertise, and provides uniform guidance to voivodeships for AQP development, could greatly improve this process. The differences in approaches to air quality planning across voivodeships provides an opportunity for stock-taking of regional experiences. Experiences from around the world indicate that the existence of an apex organization (e.g. the Ministry of Environment), is crucial in promoting coordination across regions and across different levels of government, facilitating stock-taking, identifying lessons learned and fostering knowledge exchange across regions as part of efforts to ensure consistency of approaches.

At the local level, a strengthened approach to Integrated Air Quality Management (IAQM) is needed, which is based on establishment of comprehensive and accurate emissions inventories, prioritizing residential and transport sectors. The establishment of complete and accurate emission inventories, which adequately capture all sources of polluting air emissions, is the bedrock of IAQM, an approach that is based on source emissions and ambient air quality monitoring data; atmospheric dispersion and deposition, pollutant concentrations, health risk assessment and the costs and benefits of abating emissions. Data for residential emission inventories in Poland are often of poor quality and suffer from large uncertainties, and for these reasons likely to underestimate emissions from the residential sector. Given the prominent role of the residential sector in contributing $PM_{2.5}$ emissions, accurately capturing and inventorying the emissions of this sector are critical for effective air quality management in Poland. Similarly, information on transport sector emissions is not fully understood, especially in relation to the contributions of imported used cars, which do not have adequate emission control technology – and account for about a third of new registrations - needs to be more carefully captured. The government's ongoing efforts through the National Center for Emissions Management to strengthen emission inventory development should be continued and supported.

Poland has established an extensive national air quality monitoring network but could expand monitoring of health damaging air pollutants, including fine particles ($PM_{2.5}$), ultrafine particles, and chemical species and constituents of PM. Poland has established a comprehensive national air quality monitoring network. Monitoring of the more harmful to health $PM_{2.5}$ is a more recent development than measurement of PM_{10}. The need for $PM_{2.5}$ monitoring is underscored by recent findings of Burnett et al., 2018, which indicate that $PM_{2.5}$ may be implicated in more health outcomes than currently included in global estimates, and as such the global health burden attributable to $PM_{2.5}$ may be significantly larger than previous global estimates. Continued monitoring of $PM_{2.5}$ should be expanded and monitoring systems can be strengthened by incorporating the measurement of ultrafine particulate matter, notably black carbon, an air pollutant that also has climate warming properties. Given Poland's heavy dependence on coal, monitoring of chemical constituents and species of PM that are associated with combustion of solid fuels is also recommended. Chemical constituents and species associated with combustion sources have long- and short-term health effects and monitoring them could help to better understand such health impacts on the Polish population (World Bank, forthcoming).

Development of mandatory technical guidance for IAQM - including use of air dispersion models, and source apportionment, health impact and cost-benefit analyses in Air Quality Plans (AQPs) - is needed. Technical guidelines for conducting dispersion modeling, source apportionment and health risk assessment in AQPs is often voluntary and does not provide sufficient guidance to support the development of effective AQPs. There are various ways to improve the AQPs. They should concentrate more on quantitative rather than qualitative data. Emission inventories of the residential sector need to be greatly improved. Emission inventories are inconsistent in quality and methods used across the voivodeships. There should be consistent methods for estimating emissions from the residential sector, including standardized emission factors, applied in the same manner in all voivodeships. Background concentrations of pollutants should be incorporated in modelling in a uniform way. AQPs should include source apportionment analysis at a minimum for PM. However, there are not uniform guidelines for which models and methods to use for dispersion modeling or for source apportionment modeling. Air quality issues in some voivodeships are partially due to transboundary pollution from other parts of Poland and sometimes other countries, requiring cooperation with neighboring Voivodeships. Such needed consistent and comprehensive guidance could be developed by the Ministry of environment. Furthermore, to avoid the problem of variability or inconsistency in the quality of AQPs across voivodeships, the Ministry could play a role in reviewing and approving AQPs prepared by the voivodeships. In addition, mechanisms could be put in place to ensure that application of guidance is mandatory, for example through updates to the Regulation on air quality plans and short-term action plans.

Poland should transition toward adoption of a more health-based approach to dissemination of air quality information (air quality index). Although air quality is publicly disseminated online in real-time in Poland, the Polish Air Quality Index is not based on health criteria, and therefore underestimates the real health risks of air pollution to the public. This can be misleading in terms of representing air quality status and for informing precautionary or protective measures to be taken by sensitive groups and other members of the public. The Polish alert threshold for PM_{10} is the highest among the EU Member States. As $PM_{2.5}$ is now the foundation of air pollution health risk assessment, alerts should eventually be based on $PM_{2.5}$ concentrations.

Under its Clean Air Program (CAP), Poland has made important accomplishments notably, the recent adoption of regulations on solid fuel quality. However, strong government measures will need to be taken to enforce bans on low-quality coal fines by 2020 and to make fuel quality standards more stringent in the short to medium term especially with respect to coal quality standards for households and other small consumers. The new fuel quality regulations for small consumers include quality specifications for low-quality coal fines (grain size of 1mm-31.5mm). Coal fines can be sold until June 2020. However, enforcing the ban on its use in households may be difficult and the government will need to take strict measures, including incentives to enforce the ban. Furthermore, the new fuel quality regulations specify up to 1.7%

sulfur content for coal for small consumers. By comparison, in some other coal-consuming countries, sulfur content of hard coal, for all consumers, is: Czech Republic (0.42-0.43%); Turkey (0.8-1.0%); and Germany (0.45-1.8%).[49] The Polish government should take steps to further reduce the sulfur content of solid fuel.

The government will need to eliminate gaps in regulations that could allow boiler manufacturers to by-pass recently adopted legal technical requirements for small-scale solid fuel boilers. In October 2017, the government introduced for the first time a regulation on technical requirements for small-scale solid fuel boilers for use in residential and service sectors. The regulation prohibits the sale of the more polluting no-class, class 3 and class 4 boilers effective July 2018, and introduced emission requirements for class 5 boilers in line with the European Commission's Ecodesign Regulation. However, boiler manufacturers could find ways to by-pass the regulation for example by renaming old-type biomass boilers and selling them as "non-woody biomass" boilers and by describing no-class coal boilers originally designed for building heating as hot water heaters. Under the new regulation, installations including boilers for heating drinking water, and "non-woody biomass" boilers are excluded from the new technical requirements. The government will need to develop and enforce legislation to eliminate such gaps that could allow manufacturers to by-pass the law.

The recent enactment of the law on electromobility and alternative fuels is illustrative of the government's commitment to promote low-emission transportation. Careful consideration should be given to distributional impacts of implementing low-emission initiatives. The national Electromobility Development Plan, launched in March of 2017 envisages 1 million electric cars in Poland by 2025 and provides for a system of incentives. The law introduces the creation of low-emission zones by municipal governments in densely built-up areas. Implementation of the law provides potential opportunities for economic development, in addition to environmental improvements. Given the relatively old age of Poland's vehicle fleet and that people of lower economic status are more likely to drive older vehicles, the government could consider understanding the distributional impacts of implementing low-emission initiatives.

The government should put in place mechanisms to support the broader adoption of anti-smog resolutions (ASRs) that ban the residential use of low-quality solid fuels in voivodeships. A number of voivodeships and agglomerations have voluntarily adopted ASRs, aimed to reduce the adverse impacts of air pollution from the residential sector through restrictions on

[49] https://euracoal.eu/libraray/annual-reports/

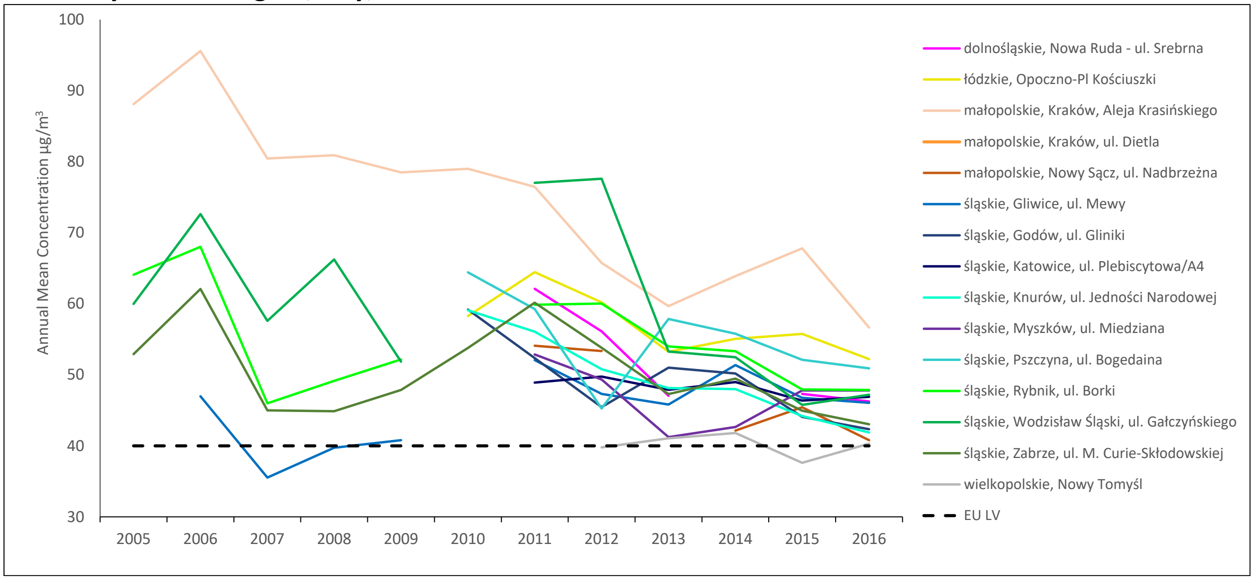
individual heating installations and solid fuels that are allowed for burning. In małopolskie voivodeship, for example, the ASR for Kraków agglomeration bans the burning of solid fuels in domestic installations, effective September 1, 2019. So far ASRs have been adopted in about 50% of voivodeships, and their wider adoption throughout the country should be encouraged and supported through appropriate financial mechanisms and strengthened public education and awareness on the provisions of ASRs.

Better tracking of funding and public expenditures enhances air quality management particularly in voivodeships where the cost of AAP is highest. Sufficient funding for air quality management is necessary to ensure that actions to reduce air pollution can be adequately carried out. In Poland, funding for environmental management comes from various sources: national, regional, international and others. The government collects fees based on emission registries, and administrative fines as penalties for exceeding permit emission limits. Payments are made by businesses and institutions which emit various pollutants, from both stationary and mobile sources. However, the residential sector is the leading contributor to PM emissions. Although in principle fees are based on the polluter pays principle, determining the effectiveness of fees in reducing pollution from fee payers merits further study. Revenues from environmental penalties are low in comparison to the monetary value of penalties imposed pointing to the need to strengthen collection of penalties: between 2015 and 2017, revenues from environmental penalties amounted to only 12-18% of the monetary value of penalties imposed.

Understanding criteria for prioritizing activities to be funded and ensuring that environmental expenditures are aligned with air quality management priorities are important for enhancing implementation effectiveness of AQPs. In some countries, public environmental expenditure reviews have been used in informing priority setting for air quality management and could be a valuable tool at the regional level, particularly in the voivodeships where the cost of health damage from ambient air pollution is highest.

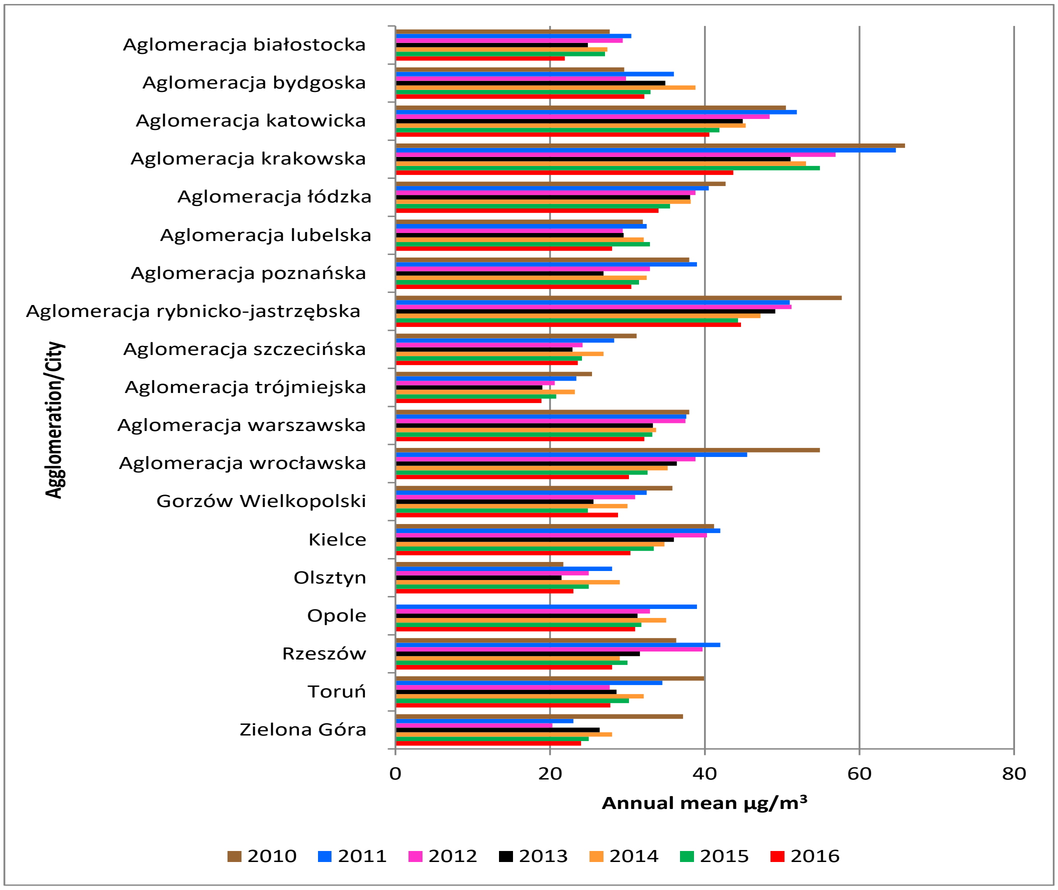
Annex A. Additional Air Quality Data

Figure A.1. Trends in Annual Mean Concentrations for PM_{10} in the Most Polluted Monitoring Sites, 2016. Key Shows: Region, City, Site Location.



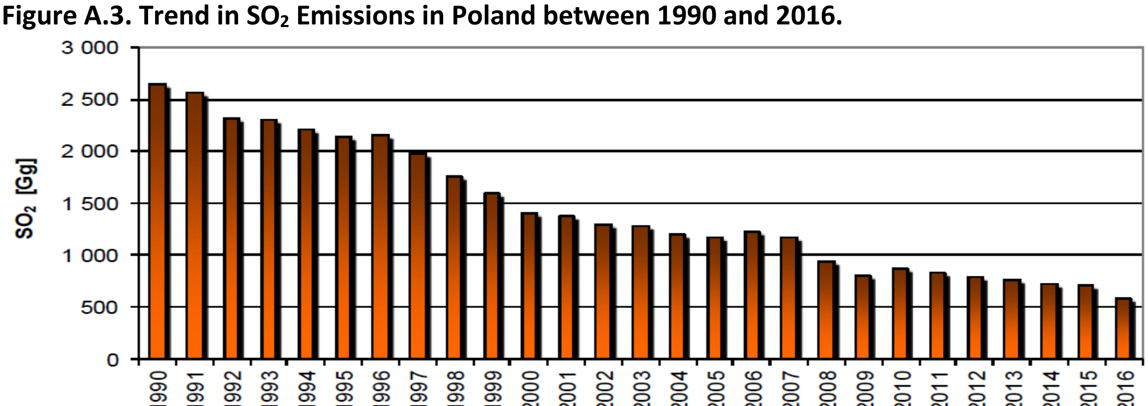
Source: Authors based on the Chief Inspectorate for Environmental Protection air quality portal.

Figure A.2. Average Annual Mean Concentrations of PM_{10} in Cities/Agglomerations Across Poland.



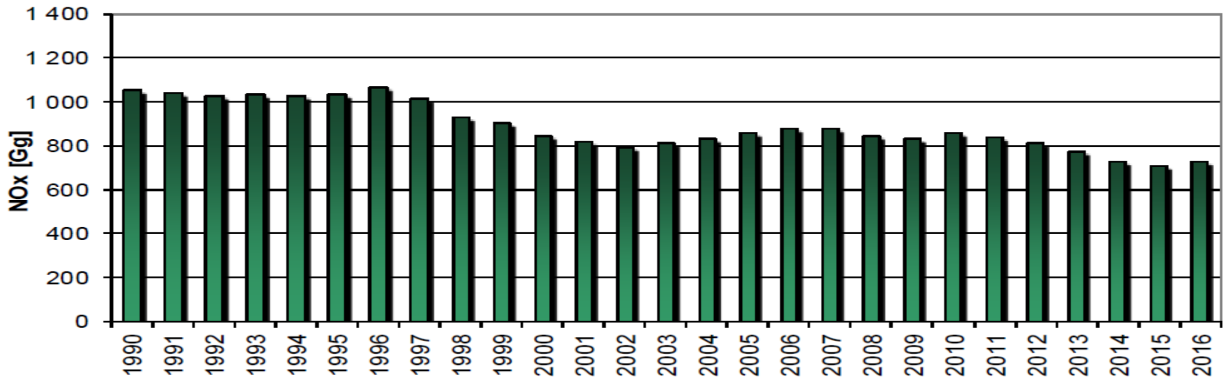
Source: Statistics Poland (2017)

Figure A.3. Trend in SO_2 Emissions in Poland between 1990 and 2016.



Source: KOBIZE, 2018.

Figure A.4. Trend in NOx Emissions in Poland between 1990 and 2016.



Source: KOBIZE, 2018.

Annex B. Valuation of mortality and morbidity attributed to AAP

Welfare approach for valuation of mortality cases

The value of statistical life (VSL) is estimated for Poland to monetize risk of a mortality cases associated with air pollution. The range in cost is due to the range of baseline VSL in OECD, as first suggested in OECD study (Lindhjem et al., 2011), and updated in Narain and Sall (2016); and different elasticity of willingness to pay (WTP) to avoid health risk. Baseline VSL is selected as the mean for high and median for low of VSL estimated in OECD studies (Narain and Sall, 2016)

For transfers between countries VSL should be adjusted with the difference in Gross Domestic Product (GDP) per capita in purchase power parity coefficient (PPP) to the power of an income elasticity of VSL of 0.6-1 (Narain and Sall, 2016, for high-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 Poland using benefits transfer method, which posits that

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

$$VSL_B = \frac{VSL_{P\ in\ PPP}}{PPP}$$

where

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

Table B.1 presents the derivation of a range of VSL for Poland on a national level from low-end (US$1.22 Mn.) and high end (US$1.58 Mn.) VSL estimates in OECD countries (Narain and Sall, 2016), using the above formula. This range of adjusted VSL is used in welfare-based estimates in this report.

Table B.1. **Benefit transfer of VSL for Poland**

	Low	High
Average VSL estimates from OECD (million US$)	3.6	4.1
Country's GDP (US$ billion) in 2016	477	477
Country's GDP PPP (US$ billion) in 2016	1,020	1,020
Population (million) in 2016	38	38
GDP per capita (PPP US $) in 2016	26,842	26,842
Average GDP/capita differential	0.73	0.73
Income elasticity of VSL	1	0.6
PPP	2.14	2.14
VSL transferred to Poland (million US$)	1.22	1.58

Source: estimated by authors

For the welfare-based mortality valuation in each voivodeship, we estimate VSL for each voivodeships in Poland, using the same approach, as for the VSL estimated on the national level.

Forgone output for valuation of mortality cases

The expected loss of income for the average person after his death attributed to AAP is valued as

$$PV(I) = \sum_{i=0}^{T} I(1+g)^i/(1+r)^i$$

where

I	=	an average per capita labor income in the present year
T	=	the expected number of working years for the average person in a particular age group (conditional on survival probabilities (78 years expected life time in Poland), and labor force participation rates[50])

50 Statistical Yearbook of the Regions in Poland, 2017

g	=	the annual rate of income growth (2% for Poland)
r	=	the social discount rate (3 % for Poland).

Since average mortality from ischemic heart disease (IHD), stroke, lower respiratory illness (LRI) and chronic obstructive pulmonary disease (COPD) occurs around 65 years of age, and from lung cancer (LC) at 60 years of age, the formula of the forgone income generates the value of mortality at this age at US$56.4 thousand on average in Poland. The estimate is adjusted for labor force participation rate (0.55) and survival rate from 60 or 65 to 75 in Poland (0.7 or 0.76).

For the Forgone Output mortality valuation in each voivodeship, we estimate forgone income generated in each voivodeship in Poland, using the same approach, as for the forgone income estimated on the national level.

Valuation of morbidity cases – Cost of Illness Approach

Cost of Illness approach based on cost of treatment and value of time lost due to morbidity case, is used to valuate morbidity. Morbidity unit cost in this study is not differentiated among different voivodeships because of the lack of information. Table B2 presents the estimated unit cost by the case of morbidity. The baseline data that are used to estimate the cost per case of illness is presented in table B3. The value of time for adults is based on average wage in Poland (US$48 in 2016). Economists commonly apply a range of 50 percent of wage rates to reflect the value of time. Hence 50 percent of this rate has been applied for both income earning and non-income earning individuals. There are two reasons for applying the rate to non-income earning individuals. First, most non-income earning adult individuals provide a household function that has a value. Second, there is an opportunity cost to the time of non-income earning individuals, because they could choose to join the paid labor force.

Table B.2. Estimated Unit Cost by the Case of Morbidity

	Cost Per Case (US$)	Cost-of-Illness Per Case (US$)	Source:
Bronchitis children, 6-12 years of age		306	Estimated by authors
Chronic bronchitis adults		3,493	Estimated by authors
CV hospital admissions		1800	Estimated from Epstein et al. (2008)

Respiratory hospital admissions		430	Estimated from Bandurska, et al. (2017)
Lost work days (adults)	31-72		Estimated by authors from Statistical Yearbook of the Regions in Poland, 2017

There is very little information about the frequency of doctor visits, emergency visits and hospitalization for chronic bronchitis (CB) patients in any country in the world. Wouters et al. (2003) and Niederman et al. (1999) provide some information on this from the United States and Europe.[51] Figures derived from these studies have been applied to Poland. Estimated lost workdays per year are based on frequency of estimated medical treatment plus an additional 7 days for each hospitalization and one extra day for each doctor and emergency visits. These days are added to reflect time needed for recovery from illness.

To estimate the cost of a new case of CB, the medical cost and value of time losses have been discounted over a 20-year duration of illness. An annual real increase of 2 percent in medical cost and value of time has been applied to reflect an average expected increase in annual labor productivity and real wages. The costs are discounted at 3 percent per year.

Table B.3. Baseline Data for Cost of Morbidity Case Estimation

	Baseline	Source:
Cost Data for All Health End-Points:		
Cost of hospitalization (US$ per day)	205	WHO-Choice adjusted to 2016 with GDP deflator, Bandurska, et al. (2017).
Cost of emergency visit (US$)	430	
Cost of doctor visit (US$)	36	
Value of time lost to illness (US$ per day)	24	50% of wages in Poland
Chronic Bronchitis (CB):		
Average duration of Illness (years)	20	Based on Shibuya et al. (2001)
Percent of CB patients being hospitalized per year	1.5 %	From Niederman et al. (1999) and Wouters (2003)
Average length of hospitalization (days)	10	
Average number of doctor visits per CB patient per year	1	
Percent of CB patients with an emergency doctor/hospital outpatient visit per year	15 %	
Estimated lost work days (including household work days) per year per CB patient	2.3	Estimated based on frequency of doctor visits, emergency visits, and hospitalization
Estimated lost work days (including household work days) per year per a case of bronchitis in a child	7.3	Estimated based on frequency of doctor visits, emergency visits, and hospitalization
Annual real increases in economic cost of health services and value of time (real wages)	2 %	Estimated by authors
Annual discount rate	3 %	Narain and Sall (2016)

51 CB is a major component of COPD which is the focus of the referenced studies. 90% of COPD cases is included in CB cases

Hospital Admissions:		
Average length of hospitalization (days)	6	Estimated by authors
Average number of days lost to illness (after hospitalization)	4	

If applied for valuation, welfare cost of morbidity is based on the willingness-to-pay (WTP) to avoid or reduce the risk of illness. This measure is often found to be several times higher than the cost of medical treatment and the value of time losses (Cropper and Oates, 1992) and reflect the value that individuals place on avoiding pain and discomfort. There are however not a sufficient number of WTP studies to avoid illness from Poland. Narain and Sall (2016) advise against transfer of the welfare cost of illness because this cost is strongly influenced by national context and is often measured in a different way. Unit cost values for different morbidity endpoints vary widely, even among countries with similar income levels. For this reason, the cost-of-illness (COI) approach (mainly medical cost and value of time losses) is used in this study to value morbidity.

Annex C. Additional Details Related to the GAINS Projections

Solid fuel use in the residential sector and structure of heat supply

Table C.1 compares total coal and fuelwood use as estimated by different studies with the data adopted for the GAINS model.

Table C.1. Reported and estimated use of solid fuel use in residential sector in Poland in 2015.

Fuel type	Million tons	Million tons	Million tons	Million tons
Source	(KOBIZE,2016)	(Stala-Szugaj, 2017)	(CSO, 2017b)[52]	GAINS
Hard coal	~ 9.5		10.3	
Coal muds	> 2	12.01	~ 1	~ 14
Flotation residues	~ 1		~ 2	
Lignite	~ 1	-	~ 0.5 - 1	~ 0.6
Total coal	**~ 12**	**12.01**	**13.5 – 14.5**	**~14.5**
Source		(ECE, 2018)	(Stove Summit, 2017)	GAINS
Fuelwood		14-15	6-8	~ 10

According to the Central Statistical Office (CSO, Polish: GUS), the heat demand in Poland in 2015 was met by (CSO, 2017b):

- Central heat supply (district heating): 41%
- Individual heating systems fueled by solid fuels: 47%
  - 23% - boilers (2 functions: heat + hot water)
  - 14% - boilers (1 function)
  - 6% - tile stoves
  - 4% - fireplaces/room heaters
- Individual heating systems (boilers) fueled by gas: 9%
- Electric heating: 2%
- Other individual heating systems (including boilers fueled by oil): 1%

Emission factors for residential sector

Table C.2 and Table C.3 presents available PM2.5 emission factors for several types of installations and fuels (coal, biomass), including also assumed values for the GAINS model. Additional information for gas and oil installations is provided in Table C.4.

Table C.2: PM2.5 emission factors for coal and coal wastes (g/GJ)

Data source	Hard coal	Lignite	Coal muds	

52 Estimate for 2016

	Manual boiler	Automatic boiler			Flotation residues
KAWKA programme (NFEP&WM) – emission sources below 50 kW	360[1]			-	-
KAWKA III programme (NFEP&WM) – emission sources below 50 kW	201	70	-	-	-
KOBIZE, 2018	115.16		100.39	-	-
Ministry of the Environment, 2003	125		125	-	-
PN EN 303-5:2012 standard – assuming 10% of oxygen in flue gases (according to U.S. EPA methodology) – Class 4	29.16	23.33	-	-	-
PN EN 303-5:2012 standard – assuming 10% of oxygen in flue gases (according to U.S. EPA methodology) – Class 5	23.33	15.55	-	-	-
Eco-design	23.33	15.55	-	-	-
EMEP/EEA air pollutant emission inventory guidebook – 2016	398 (72 – 480)	220 (72 – 230)	-	-	-
IChPW, 2017	343 (21)[2]	60 (14)[3]	423	194 (70)[4]	414
Kubica et al., 2017	27[5]	19[5]	-	-	-
GAINS model assumptions	340	120	298	n.a.	n.a.

[1] Solid fuels excluding biomass;
[2] Averaged for different coal size, in parentheses – manual boiler of Class 5 and Eco-design;
[3] In parentheses – automatic boiler of Class 5 and Eco-design;
[4] Averaged for manual boilers with natural and forced draft, in parentheses – old automatic boiler;
[5] PN EN 303-5: 2012 – Class 5 & Eco-design

Table C.3: PM2.5 emission factors for biomass (g/GJ)

Data source	Biomass – wood		Pellet
	Manual boiler	Automatic boiler	
KAWKA programme (NFEP&WM) – emission sources below 50 kW	810		-
KAWKA III programme (NFEP&WM) – emission sources below 50 kW	470	33	-
KOBIZE, 2018	226.04		-
Ministry of the Environment, 2003	180		-
EMEP/EEA air pollutant emission inventory guidebook – 2016	740 (370 – 1480)	93 (19 – 233)	-
IChPW, 2017	307 (25)[1]	28 (11)[2]	11 (7)[3]
Kubica et al., 2017	-	-	19[4]
GAINS model assumptions	372	37	33

[1] Averaged for manual boilers with natural and forced draft, in parentheses – automatic boiler of Class 5 and Eco-design
[2] In parentheses – automatic boiler of Class 5 and Eco-design
[3] Automatic boiler of Class 5, in parentheses Eco-design automatic boiler
[4] PN EN 303-5: 2012 – Class 5 & Eco-design

Table C.4: PM2.5 emission factors for gas and oil (g/GJ)

Data source	Natural gas	Heating oil

KAWKA programme (NFEP&WM) – emission sources below 50 kW	0.5	3
KAWKA III programme (NFEP&WM) – emission sources below 50 kW	0.5	3
KOBIZE, 2018	0.2	40
Ministry of the Environment, 2003	0.2	40
EMEP/EEA air pollutant emission inventory guidebook – 2016	1.2 (0.7 – 1.7)	1.9 (1.1 – 2.6)
IChPW, 2017	0.3	2
Kubica et al., 2017	0.2	-

Table C.5 presents the so called *new common emission factors* (for all pollutants) that are recommended for use by administration bodies developing emission inventory of residential sector in Poland (ATMOTERM, 2017). These factors are based on the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2016) however they take into account the specificity of the quality of fuels and the types of boilers used in Poland. At the same time, however, work on the new consistent methodology for residential sector under the NAQP continues and its completion expected by the end of 2018. This will include elaboration of guidelines for preparation of emissions inventories on *gmina* and *voivodeship* levels including unified set of emission factors.

Table C.5: Recommended emission factors for use in residential sources emission inventory development in Poland (g/GJ)

	Old boilers				**New boilers(1)**	
	Natural gas	**Hard coal**	**Wood**	**Heating oil**	**Hard coal**	**Biomass**
SO_2	0.31	400	70	8	388	20
NOx	55	120	65	74	120	65
NO_2	5.5	12	6.5	7.4	12	6.5
TSP	0.7	473	800	2	95	48
PM10	0.7	421	760	2	84	42
PM2.5	**0.7**	**326**	**740**	**1.9**	**65**	**28**
B(a)P	0.00000060	0.15	0.121	0.00008	0.055	0.0253
CO	26	4 645	4 457	48	525	537
NMVOC	1.9	484	600	0.69	27.4	14.8
NH_3	0	0.3	70	0	0.15	0
As	0.12	2.5	0.19	0.002	2	1.5
Hg(2)	0.68	5.1	0.56	0.12	5.05	5
Cd	0.00025	1.5	13	0.001	1.25	1
C_6H_6	0.0006	6.1	16.4	0.121	6.1	16.4

(1) Automatic boilers up to 2 years old
(2) Hg in the gaseous state

Source: ATMOTERM (2017)

Comparison of national emission inventory with GAINS model estimates

Table C.6: Comparison of sectoral emissions of air pollutants in 2015 - GAINS vs. national emission inventory from 2017 and 2018, thousand tons

Sector	NOx			NMVOC		
	Inv. 2017	Inv. 2018	GAINS	Inv. 2017	Inv. 2018	GAINS
Power generation	218.6	214.5	229.9	21.4	4.3	11.5
Residential combustion	90.2	90.2	71.0	110.2	110.1	141.4
Industrial combustion and processes	71.8	75.5	87.9	157.4	217.9	82.2
Fuel extraction	7.1	8.7	0.0	60.4	60.4	14.6
Solvent use	0.0	0.0	0.0	97.5	127.8	98.4
Road transport	212.6	200.0	247.7	72.1	58.6	58.9
Non-road mobile	71.7	71.9	64.8	8.9	8.9	25.2
Waste treatment	1.7	1.6	0.1	2.8	2.5	0.0
Agriculture	0.0	2.2	0.6	0.0	0.0	2.9
Sum	**673.8**	**664.7**	**701.9**	**530.6**	**590.6**	**435.1**

Sector	SO2			NH3		
	Inv. 2017	Inv. 2018	GAINS	Inv. 2017	Inv. 2018	GAINS
Power generation	387.8	398.7	398.7	0.0	0.0	0.5
Residential combustion	164.9	164.9	171.5	0.5	0.5	23.5
Industrial combustion and processes	128.4	127.3	129.9	1.1	1.1	4.3
Fuel extraction	8.5	10.6	0.0	0.0	0.0	0.0
Solvent use	0.0	0.0	0.0	0.0	0.0	0.0
Road transport	0.2	0.0	0.3	4.4	4.0	3.0
Non-road mobile	0.3	0.3	0.2	0.0	0.0	0.0
Waste treatment	0.1	0.1	0.0	1.9	1.9	1.9
Agriculture	0.0	0.0	0.2	259.2	259.8	255.6
Sum	**690.3**	**701.8**	**700.8**	**267.1**	**267.3**	**288.7**

Sector	PM2.5			BC		
	Inv. 2017	Inv. 2018	GAINS	Inv. 2017	Inv. 2018	GAINS
Power generation	13.7	12.0	16.3	0.3	0.3	0.1
Residential combustion	66.0	66.0	175.6	5.0	5.0	42.3
Industrial combustion and processes	16.8	34.1	29.3	0.5	1.0	0.6
Fuel extraction	1.7	1.7	1.8	0.5	0.5	0.0
Solvent use	1.1	1.1	4.9	0.0	0.0	0.4
Road transport	9.8	9.2	9.2	5.2	4.8	4.4
Non-road mobile	9.1	9.1	4.7	7.5	7.5	1.8
Waste treatment	5.9	1.8	0.2	0.7	0.6	0.1

Agriculture	0.5	3.5	7.1	0.2	0.2	0.1
Sum	**124.6**	**138.3**	**249.1**	**19.8**	**19.8**	**49.8**

Results of the GAINS model – mitigation scenario emissions

Figure C.1. Sectoral structure of SO_2 emissions in Poland in 2015 and analyzed scenarios for 2030

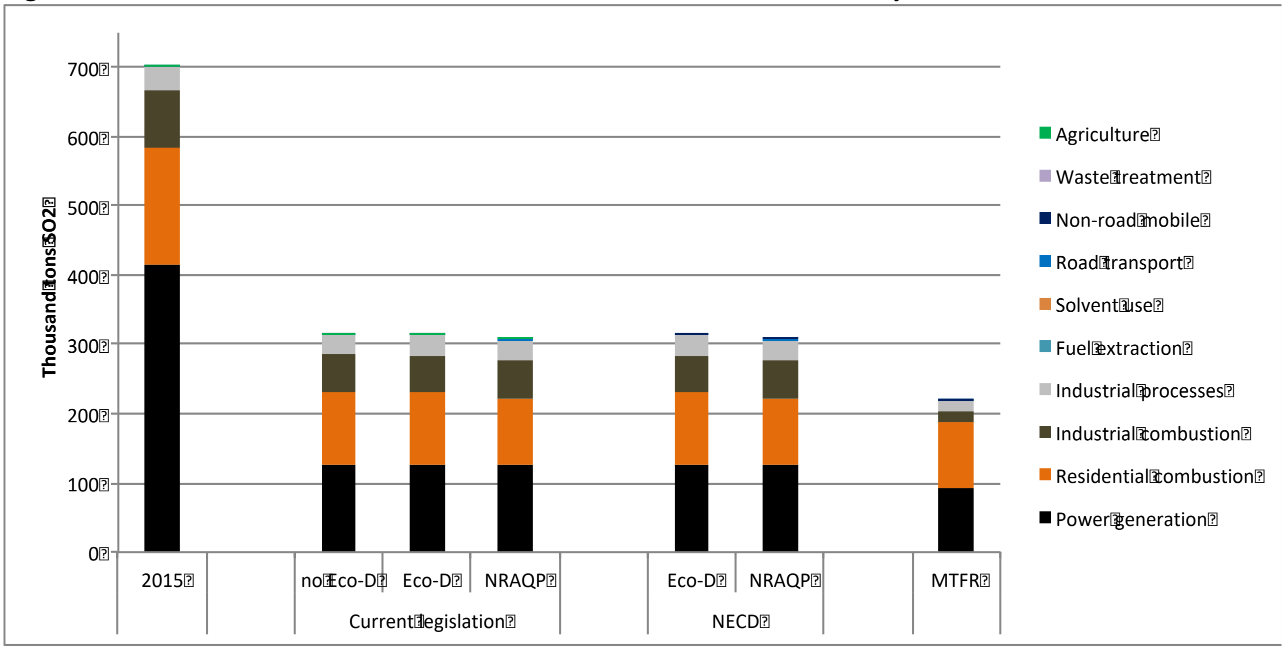


Figure C.2: Sectoral structure of NO_x emissions in Poland in 2015 and analyzed scenarios for 2030

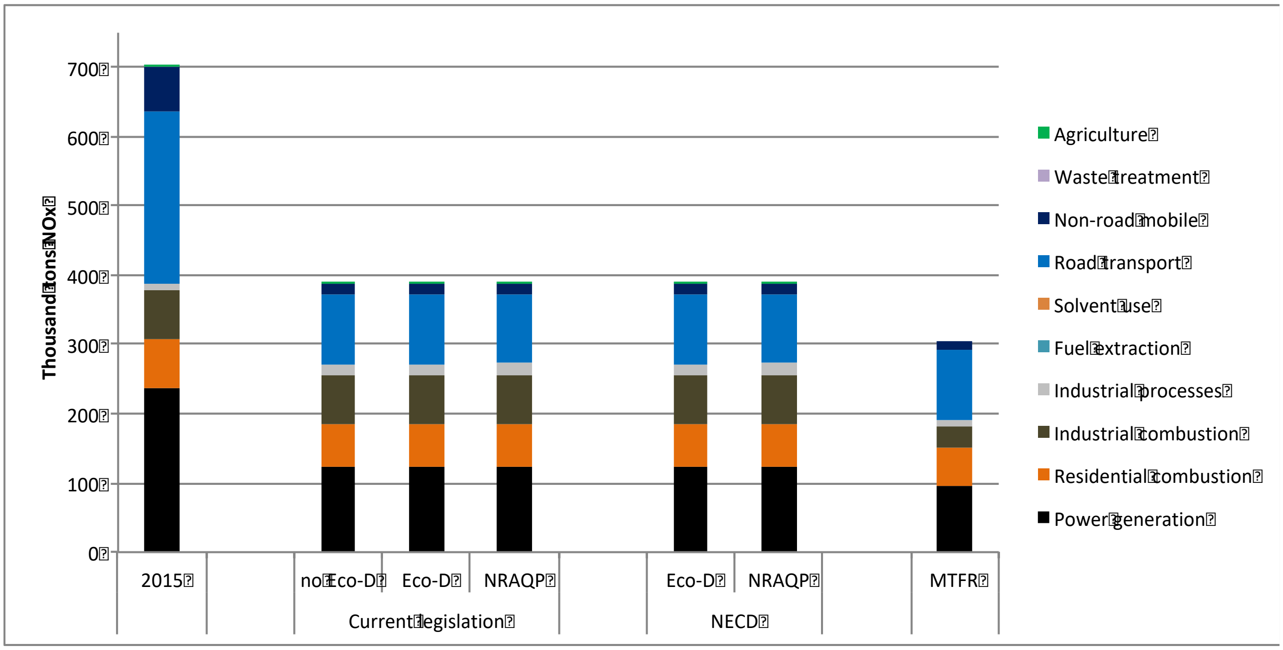


Figure C.3: Sectoral structure of NMVOC emissions in Poland in 2015 and analyzed scenarios for 2030

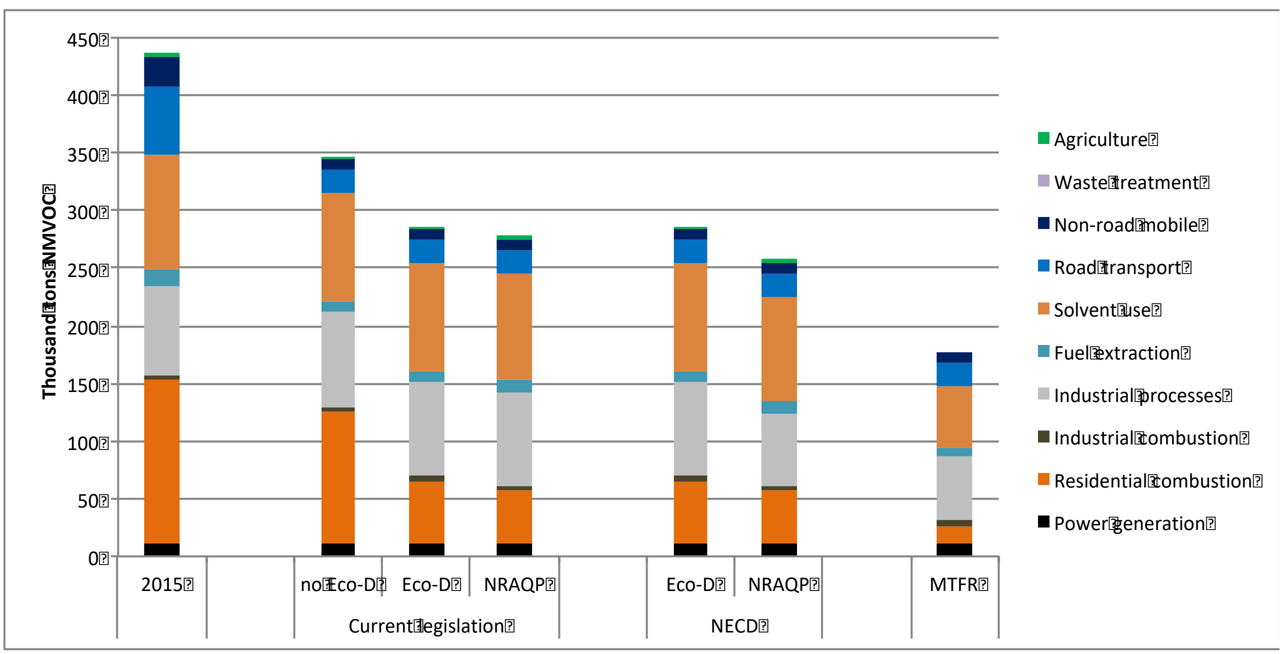


Figure C.4: Sectoral structure of NH_3 emissions in Poland in 2015 and analyzed scenarios for 2030

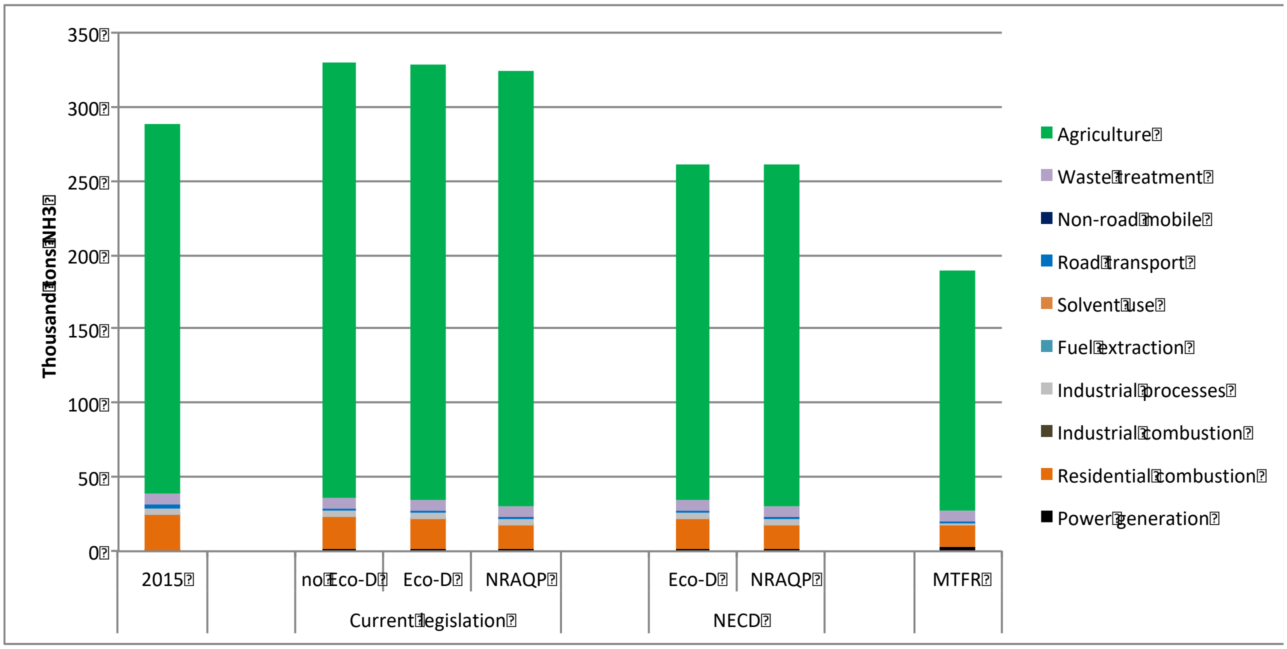


Figure C.5: Sectoral structure of BC emissions in Poland in 2015 and analyzed scenarios for 2030

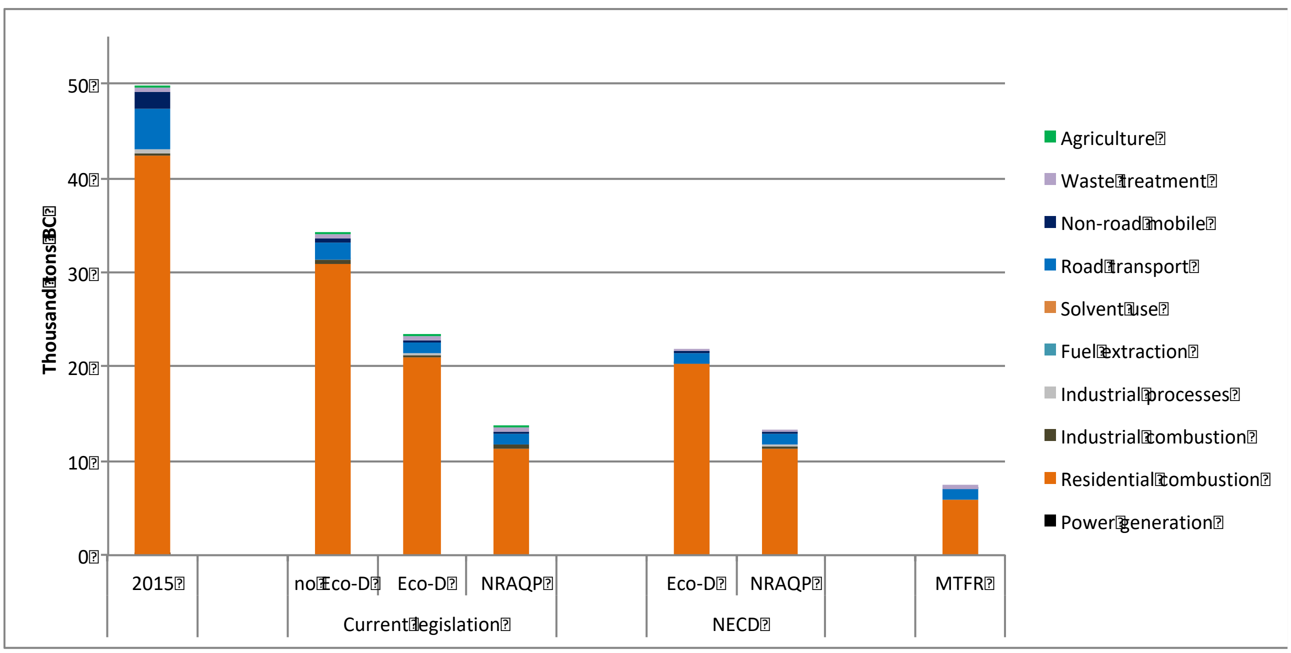


Table C.7: SO_2 emissions by key sectors (kilotons)

	2015	PRIMES 2016 REFERENCE scenario for 2030	
		Current legislation (CLE)	NECD compliant

		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	Max. red. potential (MTFR)
Power generation	414	125.6	125.6	125.6	125.6	125.6	91.2
Residential combustion	171.5	105.2	103.7	97	103.7	97	96
Industrial combustion	80.5	54.2	54.2	54.2	54.2	54.2	17.1
Industrial processes	34	29.2	29.2	29.2	29.2	29.2	14.4
Fuel extraction	0	0	0	0	0	0	0
Solvent use	0	0	0	0	0	0	0
Road transport	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Non-road mobile	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Waste treatment	0	0	0	0	0	0	0
Agriculture	0.2	0.2	0.2	0.2	0	0	0
Sum	700.8	314.9	313.4	306.8	313.2	306.6	219.2

Table C.8: NO_x emissions by key sectors (kilotons)

	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	235.4	123.6	123.6	123.6	123.6	123.6	95.5
Residential combustion	71	62.2	62.2	62.3	62.2	62.3	54.3
Industrial combustion	71	70.5	70.5	70.5	70.5	70.5	33.3
Industrial processes	11.3	15.9	15.9	15.9	15.9	15.9	7
Fuel extraction	0	0	0	0	0	0	0
Solvent use	0	0	0	0	0	0	0
Road transport	247.6	101	101	101.1	101	101.1	101.1
Non-road mobile	64.8	15.4	15.4	15.4	15.4	15.4	13.4

Waste treatment	0.1	0.1	0.1	0.1	0.1	0.1	0
Agriculture	0.6	0.6	0.6	0.6	0.6	0.6	0
Sum	701.9	389.3	389.3	389.5	389.3	389.5	304.5

Table C.9: NH_3 emissions by key sectors (kilotons)

	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	0.4	2	2	2	2	2	2.4
Residential combustion	23.5	20.6	19.6	15	19.6	15	15
Industrial combustion	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Industrial processes	4	4	4	4	4	4	1.1
Fuel extraction	0	0	0	0	0	0	0
Solvent use		0	0	0	0	0	0
Road transport	3.2	1.7	1.7	1.7	1.7	1.7	1.7
Non-road mobile	0	0	0	0	0	0	0
Waste treatment	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Agriculture	250.4	293.6	293.6	293.6	225.6	230.3	162
Sum	288.8	329.4	328.4	323.8	260.5	260.5	189.8

Table C.10: NMVOC emissions by key sectors (kilotons)

	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	11.8	10.8	10.8	10.8	10.8	10.8	10.7
Residential combustion	141.4	114.6	54.2	45.8	54.2	45.8	15.9
Industrial combustion	4.1	4.7	4.7	4.7	4.7	4.7	4.7
Industrial processes	77.8	81.2	81.2	81.2	81.2	63.3	55.5
Fuel extraction	14.6	10	10	10	10	10	8.1
Solvent use	98.4	93.6	93.6	93.6	93.6	91.2	53
Road transport	60.4	19.9	19.9	20	19.9	20	20
Non-road mobile	25.2	9.2	9.2	9.2	9.2	9.2	8.7
Waste treatment	0	0	0	0	0	0	0
Agriculture	2.9	2.5	2.5	2.5	2.5	2.5	0
Sum	436.6	346.5	286.1	277.9	286.1	257.6	176.7

Table C.11: BC emissions by key sectors (kilotons)

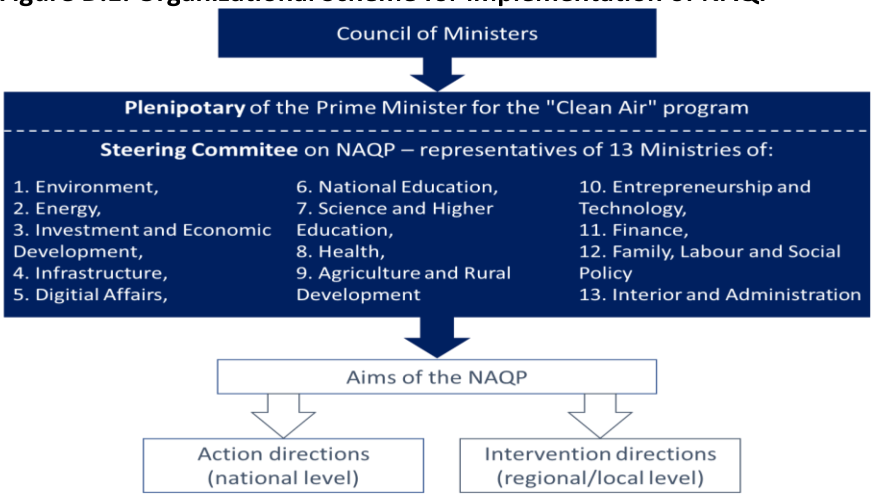
	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	0.1	0	0	0	0	0	0
Residential combustion	42.3	31	21	11.4	20.2	11.4	5.8
Industrial combustion	0.3	0.3	0.3	0.3	0.1	0.2	0
Industrial processes	0.3	0.1	0.1	0.1	0	0.1	0
Fuel extraction	0	0	0	0	0	0	0
Solvent use	0	0	0	0	0	0	0
Road transport	4.4	1.7	1.1	1.1	1.1	1.1	1.1
Non-road mobile	1.8	0.5	0.2	0.2	0.2	0.2	0.2
Waste treatment	0.5	0.5	0.5	0.5	0.3	0.4	0.3
Agriculture	0.1	0.1	0.1	0.1	0	0	0
Sum	49.8	37.9	23.3	13.6	22	13.4	7.4

Table C.12: CO2 emissions by key sectors (million tons)

	2015	PRIMES 2016 REFERENCE scenario for 2030					
		Current legislation (CLE)			NECD compliant		Max. red. potential (MTFR)
		excluding Eco-design	including Eco-design	including NRAQP	Including Eco-design	Including NRAQP	
Power generation	162.1	155.2	155.2	155.2	155.2	155.2	155.2
Residential combustion	50.2	38.0	37.4	35.9	37.4	35.9	35.9
Industrial combustion	36.4	32.6	32.6	32.6	32.6	32.6	32.6
Industrial processes	24.2	27.8	27.8	27.8	27.8	27.8	27.8
Road transport	50.3	54.3	54.3	54.3	54.4	54.4	54.4
Non-road mobile	5.8	5.5	5.5	5.5	5.5	5.5	5.5
Sum	329.0	313.4	312.8	311.3	312.9	311.4	311.4

Annex D. Additional Information on Institutional Aspects of AQM in Poland

Figure D.1. Organizational Scheme for implementation of NAQP



Source: Juda-Rezler et al., 2018

Table D.1. Overview of key EU directives related to air quality management, together with the indication of Polish legal documents transposing their provisions.

EU DIRECTIVE	POLISH ACTS AND REGULATIONS TRANSPOSING THE DIRECTIVE(s)	REMARKS
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 (so called **CAFE Directive**) Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic,	a) Act of 27 April 2001 – **Environment Protection Law** (JoL 2018, item 799, consolidated text) - **EPL** b) Act of 20 July 1991 – Environmental Protection Inspection (JoL 2016, item 1688, consolidated text, with later amendments), c) Regulation of the Minister of Environment of 24 August 2012 **on the levels of selected substances in the air** (JoL 2012, item 1031), d) Regulation of the Minister of Environment of 13 September 2012 relating to the **assessment of levels of substances in the air** (JoL 2012, item 1032), e) Regulation of the Minister of Environment of 2 August 2012 **regarding the zones in which AQ assessment is performed on the levels of selected substances in the air** (JoL 2012, item 914),	CAFE and 4DD are jointly transposed to Polish law, i.e. the normative values for substances in the air, specified in CAFE and 4DD, are included together in Regulation ***c)***. Regulations listed in ***c) – h)*** are Regulations to the **EPL**; Regulation ***i)*** is a Regulation to the Act of 22 Jur 2017 on sharing information about the environ and its protection, public participation in environmental protection and environmental impact assessments (JoL 2017, item 1405 with l amendments)

cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (4th Daughter Directive – **4DD**)	f) Regulation of the Minister of Environment of 11 September 2012 **on AQ plans and short-term action plans** (JoL 2012, item 1028), g) Regulation of the Minister of Environment of 10 September 2012 on the scope and methods of **transfer of information regarding air pollution** (JoL 2012, item 1034), h) Regulation of the Minister of Environment of 13 September 2012 on the method of calculation of the average exposure indicators, and on the method of assessment of the PM2.5 exposure concentration obligation fulfilment (JoL 2012, item. 1029), i) Regulation of the Minister of Environment of 23 November 2010 on the methods	
Directive 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC (**NEC**)	Act of July 17, 2009 on the emission management system for greenhouse gases and other substances (JoL 2009, No. 130, item 1070, with later amendments)	
Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (**IED**)	a) Regulation of the Minister of Environment of 27 August 2014 on the types of installations that may cause significant pollution of individual natural elements or the environment as a whole (JoL 2014, item 1169), b) Regulation of the Minister of Environment of October 30, 2014 on the requirements for the measurements of emission and of the amount of water consumed (JoL 2014, item 1542), c) Regulation of the Minister of Environment of 1 March 2018 on **emission standards for certain types of installations, fuel combustion sources and waste incineration or co-incineration devices** (JoL 2018, item 680).	Regulations listed in ***a) – c)*** are Regulations to the **EPL**
Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air	a) Act of 15 September 2017 amending the act - Environmental Protection Law and some other acts (JoL2017, item 1999), b) Regulation of the Minister of the Environment of 30 November 2017 amending the regulation on the types of installations whose operation requires notification (JoL 2017, item 2390),	Regulations listed in ***a)*** *and* ***b)*** are Regulations to the **EPL**

<table>
<tr><td>from medium combustion plants (MCP)</td><td>c) Regulation of the Minister of Environment of 1 March 2018 on emission standards for certain types of installations, fuel combustion sources and waste incineration or co-incineration devices (JoL2018, item 680).</td><td></td></tr>
<tr><td>Directive 2009/125/EC of the European parliament and of the council of 21 October 2009 establishing a framework for the setting of Eco-design requirements for energy-related products (Eco-design)</td><td colspan="2">The Eco-design regulations regarding boilers are to be introduced starting from January 1, 2020, as stated in the Commission Regulation (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the EU Parliament and of the Council with regard to Eco-design requirements for solid fuel boilers (OJ L 193, 21.7.2015), whose provisions will have a direct effect in Polish legislation.

Some of the requirements are already included in the Regulation of the Minister of Development and Finance of 1 August 2017 on solid fuel boilers (JoL 2017, item 1690), which is a Regulation to the EPL</td></tr>
</table>

Source: Juda-Rezler et al., 2018

Table D.2. Recommendations listed in the CAP and status of accomplishment

* - Indicates whether this issue was covered (+) or not covered (-) by the NAQP.

Recommendation		NAQP*	Status of Accomplishment	Responsibility
1	Maximum acceleration of works on the regulation **concerning requirements for solid fuel boilers**, which should be adopted by the end of April 2017 at the latest, so that its provisions will become effective before the start of the heating season 2017/2018.	+	The requirements for solid fuel boilers have been adopted in the Regulation of the Minister of Development and Finance of 1 August 2017 on solid fuel boilers (JoL 2017, item 1690), which prohibits the sale of no-class, class 3 and 4 boilers starting from July 1, 2018.	Ministry of Development
2	Urgent introduction of the regulation **on quality standards for solid fuels**, which should be adopted in the first quarter of 2017, after the introduction of amendments to the Law of 25 August 2006 on monitoring and control of fuel quality (JoL 2006, No. 169, item 1200 with later amendments).	+	The Act on monitoring and control of fuel quality has been amended and it now relates also to solid fuels sold within the residential sector – the amendment (dated March 6, 2018) was accepted by the Government. The newly adopted Regulation of the Minister of Energy of September 27, 2018 (Based on Article. 3a paragraph 2 of the Act of August 25, 2006 on the fuel quality monitoring and control system) regarding quality requirements for solid fuels sets quality requirements for solid fuels (JoL of 2018, item 427, 650, 1654 and 1669).	Ministry of Energy
3	Prioritization of the resources of NFEP&WM with preference for actions leading to the fastest possible improvement of AQ in a way leading to the	+	At the beginning of June 2018, the chairpersons of the NFEP&WM, VFEP&WMs and the Bank of Environmental Protection signed an agreement of implementation of the *Clean Air Priority Programme* in which a total of PLN 103 billion is to be allocated in 2018-2029 (PLN 63.3	Ministry of Environment

	maximum health and environmental effectiveness of the funds spent.		billon as donations and 39.7 billion as loans). The funds will be partially provided by the NFEP&WM and BOŚ. Additional EU funding is envisaged.	
4	Introduction of the requirement of gradually **connecting buildings** located in urban and suburban areas **to the heating networks** (provided that those buildings are not equipped with an effective source of heat), in such a way as to minimize the associated costs.	+	According to the Ministry of Environment and the Ministry of Energy, needed first step in addressing this recommendation is making relevant amendments to the Construction Law (JoL 2017, item 1332, consolidated text). This amendment is pending.	Ministry of Infrastructure/ Ministry of Energy/ Ministry of Investment and Economic Development/ Ministry of Family, Labour and Social Policy
5	Providing significantly reduced rates for electricity consumption during periods of reduced demand, including changes in energy and construction law regulations to encourage the installation of electric stoves or heat pumps in areas not covered by centralized district heating systems or gas networks.	–	Although the new "anti-smog" electricity rates (cheaper electricity at night) were introduced by the Ministry of Energy at the end of 2017, they are not cheaper than the cheapest tariff existing plan. The anti-smog tariff (G12as) provides cheaper energy for 8 hours at night, which can reduce the costs of electricity by around 25% in comparison to the G11 constant-price tariff. However, as calculated by experts (see portal https://enerad.pl/), existing G12 tariff (with 10 hours of cheaper energy per day) provides around 27% savings in comparison with G11. Moreover, the potential savings relate mainly to a relatively small group of people who already use the electric heating systems in their households. To change an old, solid-fuel-based heating system of a house, its owner first needs to invest a substantial sum for modernization, and the electricity costs will still be higher than the solid fuel.	Ministry of Energy (lead)/Ministry of Infrastructure/Ministry of Finance
6	**Development of the AQ monitoring network**, which should enable (1) the identification of location of	+	According to CIEP, 426 new measurement devices (such as PM samplers, analyzers for gaseous pollutants) are to be bought with funding from the EU Operational Programme "Infrastructure and Environment". 20 mobile stations were to be launched in 2018. In addition to obtain funding for the	Ministry of Environment/CIEP

	pollution sources and (2) more effective combating of harmful practices related to the handling of boilers and industrial installations.		new equipment, it will be important to ensure adequate skilled, human resources, and associated budgetary resources.	
7	**Inclusion of social assistance services** in the actions supporting boiler replacement and thermo-modernization of the buildings of poor people, in a manner that takes into account the level of generated pollution and further provision of funds for the necessary operating costs.	–	Social Welfare Centers have educational materials (prepared by the Ministry of Family, Labour and Social Policy), based on which they should inform the public on the effective use of energy in a house as well as on the possible ways to obtain financial help for boiler replacement, thermo-modernization etc. A systematic and coordinated approach of such efforts is crucial.	Ministry of Family, Labour and Social Policy (lead)/Ministry of Energy/Ministry of Infrastructure/Ministry of Environment
8	Development and implementation of a comprehensive **public policy ensuring optimal protection of the vulnerable social groups against "energy poverty**".	+	SMOG-STOP pilot programme, as well as *Clean Air Priority Programme* have been announced by the Governmental to financially support the citizens in thermo-modernization and boiler exchange. Some amendments of the Act on supporting thermo-modernization and renovations have been adopted with the aim of reducing energy poverty in Poland. The amount of funding provided for the households will depend on the financial situation of the beneficiary. SMOG-STOP will provide 23 cities (below 100 000 inhabitants) will with some financial support to perform thermo-modernization of about 15-16,000 houses in total.	Ministry of Energy/ Ministry of Family, Labour and Social Policy/ Ministry of Infrastructure

9	Conducting an educational campaign on the optimal ways of fuel combustion in boilers and related health effects.	+	In October 2017, the Ministry of Environment issued a guide (and leaflets) entitled “Clean heat from solid fuels in my house”, targeted to people using individual heating systems. In June-November 2017, the Institute of Environmental Protection conducted an informative campaign STOP SMOG, under which an informative website[53] and a short report were elaborated, and several public speeches and meetings with citizens were organized, followed by one press conference.	Ministry of Environment (leader)/Ministry of Health/Ministry of Energy
10	Introduction of the obligation to document the quality of exhaust gases by vehicle control stations and of the requirement to test the car’s exhaust gases during roadside inspections.	–	The currently proceeded amendment to the Traffic Law (JoL 2017, item 1260, consolidated text) introduces the obligation to document (archive) the results of exhaust gases examination by vehicle control stations. Car exhaust controls during roadside inspections are selectively performed by the Police: in July – December 2017, over 97 thousand controls were conducted, which led to withdrawal of almost 1400 of proofs of registration.	Ministry of Infrastructure (lead)/Ministry of Interior and Administration
11	**Using tax mechanisms to introduce incentives for low-emission transport**, including a low excise duty rate for hybrid cars and exemption from excise tax for electric cars.	–	The Act of 11 January 2018 on electromobility and alternative fuels (JoL 2018, item 317) is an implementation of this recommendation.	Ministry of Finance (lead)/Ministry of Investment and Economic Development
12	Introduction of solutions enabling the creation of low-emission zones and periodic limitation of the number of	+	The Act of 11 January 2018 on electromobility and alternative fuels (JoL of 2018, item 317) enables creation of low emission zones.	Ministry of Environment (lead)/Ministry of Infrastructure/Ministry of Energy

[53] http://srodowiskozyciem.pl

	cars in traffic within urban areas			
13	Introduction of regulations preventing blocking of ventilation corridors of the cities and consideration of raising the rank and importance of the urban planners in the context of spatial development.	–	Ventilation corridors should be included in a zoning plan for a city. However, the project of new Law on facilitating the preparation and implementation of housing investments and accompanying investments (currently elaborated by the Ministry of Investment and Economic Development) states, that investments that include at least two multi-family buildings with at least 50 flats in total do not have to comply with the Act on planning and spatial development (JoL 2017, item 1073, consolidated text), which specifies that any new investment should be consistent with a zoning plan for the respective area. Therefore, developers who are willing to build at least two blocks of flats at once will be able to do so in places where no zoning plans exist, or the existing plan stipulates other type of building e.g. single-family settlements that do not block ventilation corridors to the same extent as tall apartment buildings.	Ministry of Infrastructure/Ministry of Environment
14	Establishment of a sectoral programme at the National Center for Research and Development, whose objective will be to support the development of low-emission technologies, especially those aimed at improving AQ.	+	Sectoral programme has not been launched yet. However, proposals for projects covering tasks related to AQ improvement can be submitted to the National Center for Research and Development within the Operational Programme “Smart Growth” 2014-2020, partially financed by the European Regional Development Fund. In 2017, within the “Smart Growth” Programme there were 17 project proposals related to AQ, which were granted financing. These projects addressed industrial emissions, low-emission transport and air quality monitoring.	Ministry of Science and Higher Education
15	Ensuring the preparation of broad public consultation of the “Clean Air” Programme, as well as strengthening the Steering Committee on the NAQP and entrusting it with the task of supervising the	+	The appointment of the Plenipotentiary of the Prime Minister for the “Clean Air” Programme is an important step towards strengthening the Steering Committee.	Ministry of Environment

	urgent and effective implementation of these recommendations, including regular monitoring of the progress of the works of the Council of Ministers.			

Source: Juda-Rezler et al., 2018

Table D.3. Additional Polish laws and regulations for air quality management.

Act or Regulation	Content
Act of 27th April 2001 Environment Protection Law (EPL)	Act regulating issues related to AQM. Sets AQ standards, monitoring (and reporting) of AQ, the assessment of AQ in zones, the requirement of elaboration of AQ Plans (and/or Short-Term Action Plans – STAPs). in the case of exceedances and the obligation to report on their execution every 3 years. Anti-Smog Act & Resolutions. EPL includes 4 key AQM Regulations
Regulation on levels of selected substances in the air (2012)	Sets the limit and target values, as well as long term objectives and information and alert thresholds for the air pollutants. It transposes the AQ standards set by CAFE Directive and ensures compatibility of the AQ targets. Implements alert threshold means 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 Member States, while an information threshold means 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 is necessary. Polish alert threshold for PM10 (300 $\mu g/m^3$) is the highest amongst the Member States

Regulation on AQ plans and short-term action plans (2012)	Specifies the formal requirements that should be met by Air Quality Plans and Short-Term Action Plans. Regulation only states how the document of AQP should be organized, but does not include any guidelines on how they are to be prepared
Regulation on emission standards for certain types of installations, fuel combustion sources and Regulation on waste incineration or co-incineration devices (2018)	Introduces emission standards for various types of industrial installations of large and medium size. The standards for LCPs were in force since 2016, while the present version of Regulation adds the standards for MCPs, which will be introduced gradually, with most starting in 2025. In terms of MCPs, the new standards will concern about 4800 Polish MCP installations, including over 50% of all licensed heating companies.
Regulation on solid fuel boilers (2017)	Introduces technical requirements for small-scale solid fuel boilers used in residential sector and in services; was an execution of recommendation no. 1 from the CAP. Only class 5 boilers will be allowed to be newly installed with effect from July 2018. The requirements of class 5 boilers in terms of maximum emission of CO, VOC and PM are the same as stated in Eco-design, however they do not include a standard for NOx, covered by Eco-design. The full Eco-design regulations regarding boilers are to be introduced starting from January 1, 2020.
Act of 25 August 2006 on the fuel quality monitoring and control system (FQ)	This Law introduces a system of monitoring and quality control of liquid and gaseous fuels, it also sets out the awaited rules for controlling the quality of solid fuels sold within the residential sector, designated for combustion in households.
Regulation on quality requirements for solid fuels (JoL of 2018, item 427, 650, 1654 and 1669). September 2018	Sets quality requirements for solid fuels.

Act of 21 November 2008 on thermo-modernization and renovations	This law is one of the tools for implementation of the 15pCAP, and especially its recommendation #8 to reduce emissions and to increase energy efficiency. Introduces the term “low-emission undertaking” which is defined as an exchange of heating device/system into less emissive one, or any action resulting in decrease of heat demand of a building. Gminas will have a possibility to elaborate the so-called Gmina Low-Emission Programs (GLEP). The implementation of these programs is to be partially financed by the Thermo-modernization and Renovation Fund, however the support will only be possible for GLEPs which include: • exchange of heating devices in at least 80% of houses in the area covered by a GLEP and • decrease of total heat demand of houses in the area covered by a GLEP by at least 50%.
Act of 14 December 2012 on waste (JoL of 2013)	This Law does not relate directly to AQM, but some of its provisions are very important for the quality of air, as it is forbidden to combust waste in installations other than waste incineration or co-incineration plants. Thanks to the public pressure and critical opinions of the Polish Smog Alert, this provision starts to be applied more often, resulting in more frequent controls of combustion devices and fuels used in individual households. In Warsaw, the Municipal Police has been equipped with five so-called “smog-cars” – mobile laboratories which help conducting reliable controls and provide reasons for assigning fines.
Act of 11 January 2018 on electromobility and alternative fuels	One of the first steps to implement the national Electromobility Development Plan, which assumes that by 2025 there would be up to 1 million electric cars in Poland. It provides for a system of incentives for the abolition of excise duty on electric cars and plug-in hybrids (PHEV) (for the latter until the end of 2020), the release of electric cars and PHEV from parking fees and permission to drive on bus lanes (until 2026) and for larger depreciation write-offs for companies using electric cars and PHEV.

Source: Juda-Rezler et al., 2018

Poland's 46 air quality zones are shown in Figure D.2. Within each zone air pollution must be monitored to determine compliance with the Limit Values (LVs). The pollutant concentrations are compared to the LVs on an annual basis. Each zone is classified as A (does not exceed) or C (exceeds) for each pollutant depending on whether the LVs are exceeded. In zones classified as C, activities include specifying the areas where limit levels are exceeded, developing or updating the air protection program to achieve appropriate limit levels for pollutants in the air, and controlling pollutant concentrations in the areas where limit levels were exceeded and conduct activities to decrease the concentrations at least to the limit level values. If the problem is with pollutants with Target Values, then activities should strive to achieve the target value for the substance within a specified time using economically reasonable technical and technological measures and develop or update the air protection program to achieve appropriate target values.

Figure D.2. Air quality zones in Poland

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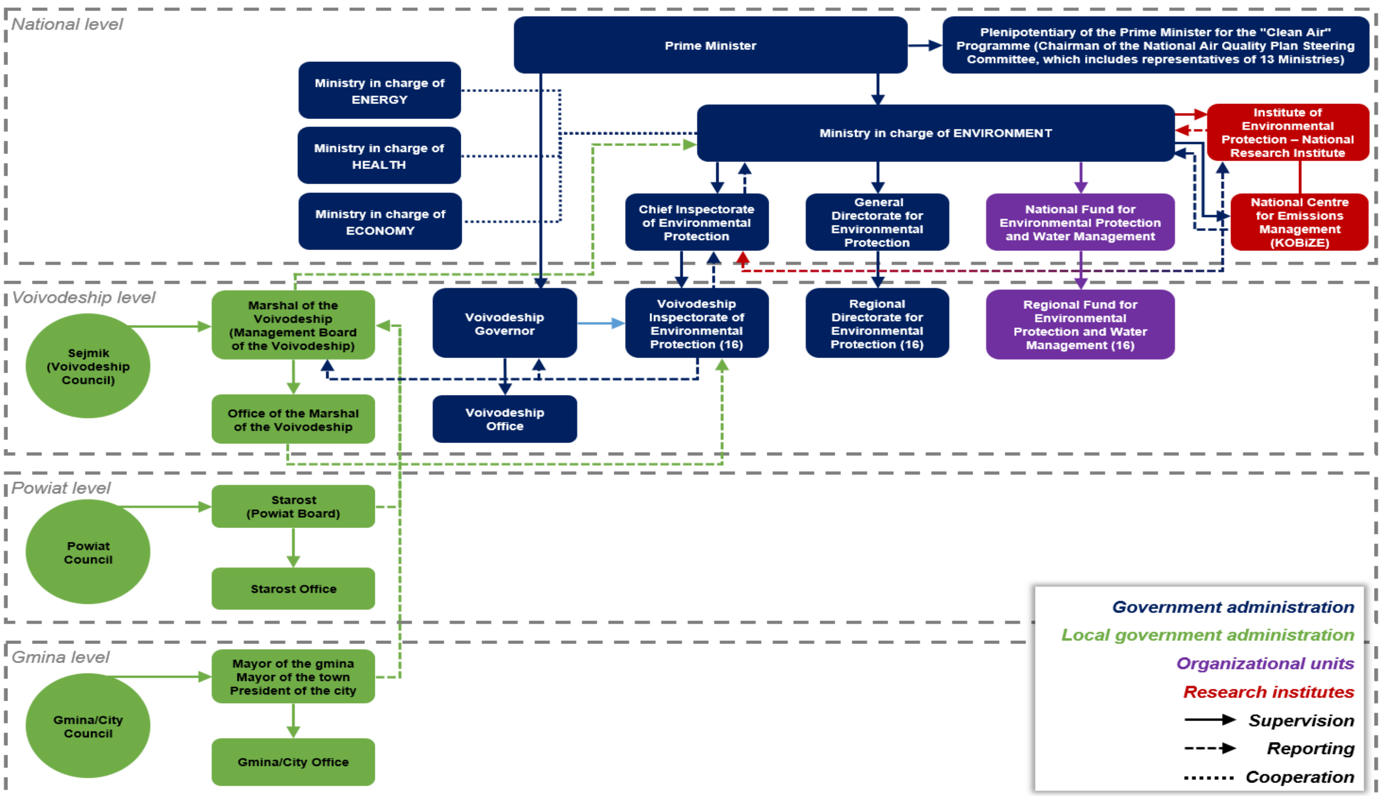
Source: European Commission Environment web portal[54]

[54] http://ec.europa.eu/environment/air/quality/zones.htm

Air Quality Management requires the interaction of many stakeholders, including the representatives of more than 65 governmental administration authorities and bodies, research institutes, and more than 5600 local governmental administration authorities (Figure D.3). The administrative reforms of 1999 established a three-tier territorial system in Poland. The country is divided into voivodeships, which are further divided into powiats, and these in turn are divided into gminas. Major cities e.g. Warsaw and Kraków, have dual status as gmina and powiat. The reforms significantly reduced the central government's administrative presence at the sub-national levels. The state has decentralized responsibilities and financial capacities to democratically elected regional governments.

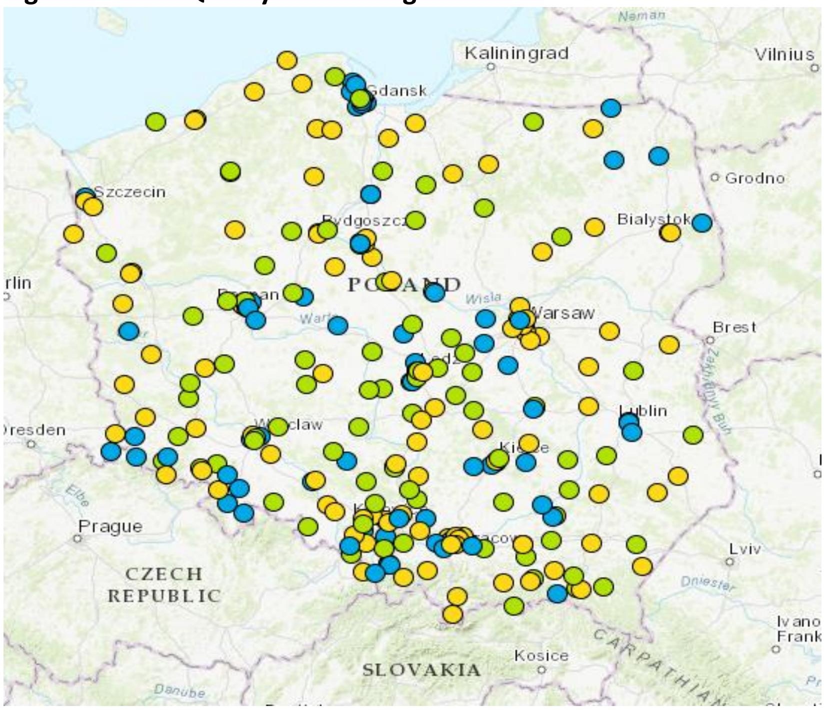
Figure D.3. Key Entities for Air Quality Management in Poland.

Source: Juda-Rezler et al., 2018



Poland's State Environmental Monitoring for air quality is comprised of 310 stations (**Error! Reference source not found.**).

Figure D.4. Air Quality Monitoring Network in Poland.



Source: Air Quality Portal of Chief Inspectorate for Environmental Protection.

The World Air Quality Index[55] uses 5 categories – Good, Moderate, Unhealthy (for sensitive groups), Unhealthy, Very Unhealthy, and Hazardous. This index was adapted from the Air Quality Index of the US Environmental Protection Agency[56], which is based on analyses of health assessment of the main air pollutants. The index classes for PM set under the PAQI do not appear to be based on health assessment.

Table D.4. Thresholds for PM_{10} and $PM_{2.5}$ Concentrations Used in Polish Air Quality Index (PAQI) and European Air Quality Index (EAQI).

PAQI level	PM10 [$\mu g/m^3$]	PM2.5 [$\mu g/m^3$]
Very good	0 – 21	0 – 13
Good	21 – 61	13 – 37
Moderate	61 – 101	37 – 61

EAQI level	PM10 [$\mu g/m^3$]	PM2.5 [$\mu g/m^3$]
Good	0 – 20	0 – 10
Fair	20 – 35	10 – 20
Moderate	35 – 50	20 – 25

55 https://waqi.info/
56 https://cfpub.epa.gov/airnow/index.cfm?action=aqibasics.aqi

SUFFICIENT	101 – 141	61 – 85
BAD	141 – 201	85 – 121
VERY BAD	> 201	> 121

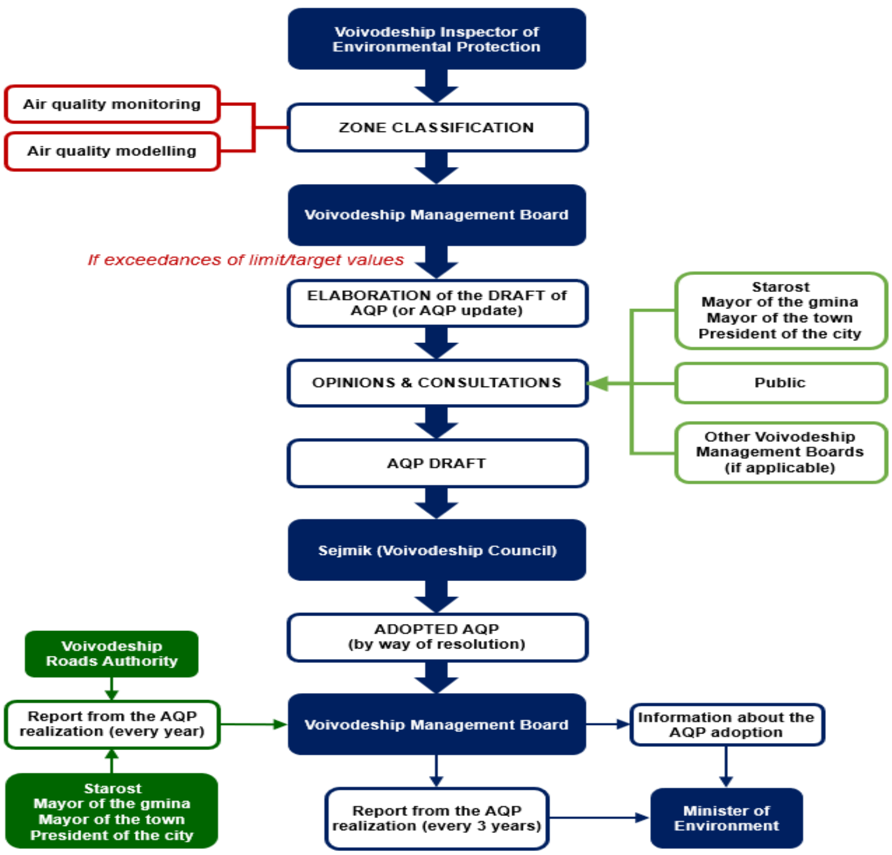
POOR	50 – 100	25 – 50
VERY POOR	> 100	> 50

Source: Juda-Rezler et al., 2018

Air Quality Planning at the Sub-National Level

The legislative process for developing and implementing Air Quality Plan is shown in **Error! Reference source not found.**.

Figure D.5. Legislative Process for AQP Development



Source: Juda-Rezler et al., 2018.

Table D.5. Specific Pollutants in Polish Air Quality Plans

Pollutant	PM_{10}	$PM_{2.5}$	B(a)P	NO_2	O_3	As	CO	C_6H_6
Number of AQ zones with AQPs that address pollutant	42	27	46	4	10	4	2	2

Source: Juda-Rezler et al., 2018

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