AIR QUALITY IN BISHKEK

ASSESSMENT OF EMISSION SOURCES AND ROAD MAP FOR SUPPORTING AIR QUALITY MANAGEMENT

October 2022

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LIST OF ABBREVIATIONS

AOD	Aerosol Optical Depth
AQ	Air Quality
AQI	Air Quality Index
AQMN	Air quality monitoring network
AUCA	American University of Central Asia
CHP	Combined heat and power station
CLRTAP	Convention on Long-range Transboundary Air Pollution
CNG	Compressed Natural Gas
CO	Carbon monoxide
EEA	European Environmental Agency
EMEP	European Monitoring and Evaluation Programme
EU	European Union
FMI	Finnish Meteorological Institute
GDP	Gross domestic product
HOB	Heat only boilers
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquified Petroleum Gas
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDC	Nationally Determined Contribution
NGO	Non-governmental organization
NMVOC	Non-methane volatile organic compound
NO	Nitrogen monoxide
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
O_3	Ozone
OMI	Ozone Monitoring Instrument
PAH	Polycyclic aromatic hydrocarbons
PM_{10}	Particulate matter (diameter less than 10 μm)
$PM_{2.5}$	Particulate matter (diameter less than 2,5 μm)

$PM_{1.0}$ / PM_1	Particulate matter (diameter less than 1,0 μm)
POPs	Persistent organic pollutants
QA/QC	Quality Assurance/Quality Control
SO_2	Sulphur dioxide
TSP	Total Suspended Particulate
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
US	United States of America
US EPA	US Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organization
WMO	World Meteorological Organization

SUMMARY FOR POLICYMAKERS

1. This study is the first comprehensive analysis of key emission sources and their impact on ground-level air pollution concentrations in Bishkek, thus providing decision-makers for the first time with scientific evidence for policy-making.

The study analysed air quality monitoring data (2015-2021), developed and analysed emissions inventories, conducted local-scale dispersion modelling and analysed satellite data. Results of this study, including the *Roadmap for Implementation of the Priority Policies and Measures* can be used to prioritise air pollution interventions, focusing on what actions will result in the biggest health gains. This study provides an important foundation for other research to build on, opening the door for further understanding Bishkek's air pollution, its sources and impacts, and how to improve air quality.

2. Bishkek experiences poor air quality throughout the year, with extremely dangerous levels during the wintertime heating period (approx. October – March).

Across 2010-2019, 12-13% of all annual deaths in Kyrgyzstan were attributed to air pollution, corresponding to between approximately 4 100-5 000 deaths annually. The health costs of air pollution in Kyrgyzstan were estimated at USD 388 million or 6% of Gross National Income in 2015. Reductions in air pollution levels can reduce the burden of disease such as stroke, heart disease, cancer, and chronic and acute respiratory diseases, including asthma.

3. Reducing fine particulate matter ($PM_{2.5}$) pollution is the highest priority, as exposure to high concentrations causes the most severe health impacts. This study found that in Bishkek, annual mean $PM_{2.5}$ concentrations are around 30 μg/m^3, exceeding by far Kyrgyzstan's national and all international (EU, US EPA and WHO) health-based limits and guideline values (for example, WHO guidelines for annual concentrations is 5 μg/m^3). Concentration levels of $PM_{2.5}$ peak in the wintertime to many times over shorter-term national limit values. Thus, actions that reduce $PM_{2.5}$ should be prioritised in order to reduce the population's exposure to fine particulate matter and to reduce the greatest health impacts of air pollution.

4. The most dangerous levels of fine particulate matter ($PM_{2.5}$) pollution are caused by residential heating with (sulphur-rich) coal during the wintertime exacerbated by poor mixing conditions of the air. Attention should be paid first and foremost to reducing emissions from private housing.

This study identified the main cause of the wintertime $PM_{2.5}$ pollution as residential heating – that is, private houses not connected to the Combined Heat and Power station (CHP) grid burning low grade sulphur-rich coal for heating. Policies that incentivise households to use heating sources other than coal, such as heat pumps or electric heating provided by substantially increasing the capacity of renewable energy generation, will greatly benefit air quality in Bishkek. Measures that enhance the energy efficiency of new and old houses and buildings and reduce energy needs would also significantly improve air quality.

5. Action plans should be developed for episodes with severe or poor air quality.

Air quality can deteriorate quickly for short or longer periods. Daily air pollution alerts, particularly during the wintertime, can provide information and recommendations to the public, so that they can take actions to protect their health.

6. Emissions from the CHP have a limited impact on ground-level air pollution in Bishkek, and therefore actions aimed at reducing emissions will likely have only minimal impact in reducing people's exposure to air pollution in Bishkek.

This study was the first to model emissions from the CHP and their impact on ground-level concentrations of various air pollutants. Results show that the CHP has little impact on ground-level pollution concentration levels of fine particulate matter ($PM_{2.5}$), sulphur dioxide (SO_2), and nitrogen dioxide (NO_2) during most meteorological conditions. Analysis indicated that the CHP may contribute less than 1% to ground-level pollution concentrations of $PM_{2.5}$ and PM_{10}, and less than 10% to ground-level SO_2 levels in other parts of the city. So, whilst emissions may be high compared to other sources, the CHP is not the primary cause of Bishkek's most dangerous levels of wintertime air pollution. The tall stack (chimney) heights mean that pollution is dispersed along the Chui valley and away from Bishkek, and emissions control equipment is in use. During wintertime, Bishkek experiences periods where meteorological conditions create a surface layer of air in which mixing is greatly supressed, and this creates an unfavourable situation for air quality. However, the top of the main CHP stack is often above this layer, and consequently emissions disperse away from the surface. So, while controlling CHP emissions may not be the highest priority for improving air quality in Bishkek, it is essential to rapidly transition away from fossil fuels to low-emissions renewable energy sources in line with the climate agenda.

7. Transport is another key source of air pollution in Bishkek.

According to the emissions inventories developed during this assessment, road transport is the greatest source of nitrogen oxides (NO_x) and a considerable source of fine particulate matter ($PM_{2.5}$). The greatest health impacts in urban areas are typically due to $PM_{2.5}$, but high NO_x concentrations are also important. Traffic emissions typically have a significant impact on air quality as they are released into the air near ground level. NO_2 annual mean concentration levels measured in the Bishkek urban background area are around 40 µg/m^3, which exceeds the WHO guideline values, equals the EU limit value level and is below the US EPA limit value. It is likely that NO_2 concentrations are higher in traffic environments compared to those seen at the urban background station. More data on transport is needed, such as accurate information on vehicle numbers, fleet characteristics, activity levels, fuel type use and distribution, to prepare emission maps of the road network and show where in Bishkek the largest emissions from transport arise. Similarly, monitoring of air pollution (particularly NO_2) in traffic environments is needed to more accurately understand the impact of transport emissions on air pollution levels.

8. Actions to reduce emissions from transport are also a priority and include reducing tailpipe emissions (via catalytic converters, emissions regulations, reforming fuel standards) and major improvements and investments in public transport.

Other policies, such as phasing out of older heavy-duty vehicles from city roads, will also reduce emissions from transport.

9. Improving waste management will reduce toxic air emissions.

Bishkek has a large landfill area, the Bishkek Authorized Dump Site. The landfill area has a continuous uncontrolled fire that has a strong impact on the air quality in surrounding areas. Uncontrolled burning of the waste causes many toxic compounds and carcinogenic air pollutants such as polycyclic aromatic hydrocarbons which poses a risk to human health, particularly on the people living nearby. Steps need to be taken to control the fire to the extent possible. More broadly, improving the city's waste management, such as through the introduction of waste separation and recycling can reduce the amount of waste going to landfill, and modern waste to energy plant technologies can be used to generate heat and electricity.

10. Emissions of all key pollutants are expected to grow significantly towards 2040 under a 'business as usual' scenario.

An emissions inventory was developed for Bishkek providing annual estimates of priority air pollutants since 2000, and emission projections out to 2040. By 2040, $PM_{2.5}$ emissions are estimated to increase by three-fifths (60%), driven predominately by increases in emissions from residential combustion; NO_x emissions are estimated to increase by almost two-thirds (63%), driven largely by increased emissions from transport, notably petrol-powered cars; and SO_2 emissions are estimated to increase by half (50%), driven by emissions from CHP. It is important to note that emissions volumes do not correspond directly to ground-level pollution concentrations. For example, smaller emission sources located closer to ground level height can cause higher pollutant concentrations than larger emissions volumes released higher (e.g. through tall stacks or chimneys). Thus, understanding the context of emissions, and where possible, modelling emissions dispersion, is important for correctly identifying the key causes of ground-level air pollution.

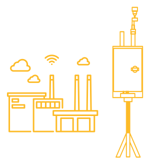
11. Individuals have limited opportunities to control air pollution, thus action by local, national, and regional level policymakers is needed. Emissions reductions can be achieved across many sectors, including energy, transport, housing, power generation, and municipal and agricultural waste management.

Affordable access to clean household energy solutions and improvements in energy efficiency can be expanded. Emissions from transport can be reduced through "Avoid, Shift, Improve" policies, by avoiding unnecessary transport use through enhanced urban planning, through shifting to greener forms of transport, and improving technologies used in transport to decrease emissions. Energy efficiency of buildings can be improved, reducing energy demand. Emissions from power generation can be reduced through transitioning to low-emissions fuels and renewable combustion-free power sources such as solar, wind and hydropower. Strategies supporting waste reduction and separation, recycling and reuse, and application of best available technologies can reduce emissions from municipal and agricultural waste.

12. The WHO Air Quality Guidelines were updated in 2021 and provide an assessment of the health effects of air pollution and thresholds for health-harmful pollution levels. **Reducing air pollution in line with WHO guidelines is a priority, and can be done by achieving a set of interim targets through stepwise reduction of air pollution levels.**

13. Air quality management in Bishkek needs to be strengthened to protect against thehealth and environmental impacts of air pollution.

Some air quality monitoring is being undertaken, and decision-makers have designed and implemented air pollution reduction policies to a limited extent. However, current governmental air quality management tools are insufficient in providing reliable air quality data to further support decision-making and inform citizens about air quality. Both a reliable, high quality monitoring network and a detailed high-quality emissions inventory are needed to assess the state of air quality and to analyse the impact and effectiveness of air pollution control measures that have been implemented. It is important that these are established and then supported across long-term timescales.



Air quality monitoring is one of the cornerstones of air quality management. There is a need to improve Bishkek's air quality monitoring network by establishing more reference-level air quality monitoring stations for compliance monitoring and to enhance the capacity of expert organization responsible for operating the network, processing and analysing data.

The current air quality monitoring network is not sufficient for providing reliable air quality data to support decision-making and to inform and protect citizens. Air quality monitoring stations need to meet modern quality standards for air quality monitoring, to be situated in locations that represent different environments and areas (traffic, industry, urban background, and rural background), and to measure priority air pollutants, including particulates ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x, NO_2), sulphur dioxide (SO_2), ozone (O_3) and carbon monoxide (CO). Improving air quality monitoring will enable a more in-depth understanding of air pollution in Bishkek, such as greater insights into its spatial variations, enabling policymakers to implement effective policy interventions. Setting up a reference level air quality monitoring network requires considerable long-term investments and operation and maintenance costs, but will provide accurate information on air quality and generate data for analyzing key emissions sources ensuring that policy-making is evidence-based.

Low-cost air quality sensors have played a significant role in informing the population about air pollution in Bishkek, and providing actionable information on air quality to the public.

There are an increasing number of low-cost air quality sensors and sensor networks in Bishkek city operated by different organizations, including by the state hydrometeorological service, KyrgyzHydromet. Low-cost sensors are indicative, user-friendly and affordable air quality monitoring tools. Sensors are used to supplement reference-level monitoring station networks and to inform the public about air quality in real-time. Dense sensor networks, such as those in Bishkek, can also provide a map of air quality across the city, and can be used to assess air quality hotspots and to plan the locations of the reference level monitoring stations. Currently, low-cost sensors do not meet the requirements of EU compliance monitoring; however, low-cost sensors remain an invaluable tool for providing indicative information on air quality, for identifying air pollution hotspots, and for supporting the development of more sophisticated monitoring networks, and are particularly useful in resource-poor environments.

Modernizing air quality legislation and effective coordination and management of the systems that support air quality management is essential.

Existing legislation is based around defined maximum allowable concentrations (MACs) and does not align with international norms that are based on the latest science about the negative impact of air pollutants. So, modernisation of the existing legislation is needed. Similarly, enhancing the air quality management process in national legislation is important to define a nominated institution mandated to coordinate, manage, and supervise the air quality management process.

14. Air pollution and climate change are interlinked and tackling air pollution is part of the climate agenda.

Burning of fossil fuels is by far the largest source of air pollution. Reducing the use of fossil fuels is therefore not only a priority for improving air quality, it is also a priority action for climate change mitigation. Thus, the vast majority of air pollution prevention actions also strongly support climate change mitigation and vice versa. Moreover, investments in climate action often pay off quickly in the short-term through air quality co-benefits via savings in the health sector.

TECHNICAL SUMMARY

This report presents the scientific background on air quality in the Bishkek area, an overview of the process of identifying the priority emission sources impacting air quality, and the new roadmap for air quality management to improve the air quality. The aim of the study was to assess air quality in Bishkek and to support air quality management to tackle air pollution and to improve the air quality.

The air quality assessment presented in this report is based on a comprehensive analysis of available air quality monitoring data from several years from both reference level air quality monitoring stations and air quality sensors located around Bishkek city. Meteorological, geographical and satellite data has also been used in the assessment. Emission inventories for the current situation, and for future emission scenarios for the Bishkek area have been compiled and calculated in this study. The air quality assessment has also been supported by case study analysis for selected emissions sources. The impact of Bishkek's Combined Heat and Power Station (CHP), and domestic heating from private houses were investigated by using the Gaussian urban scale dispersion modeling system, UDM-FMI, to study the impact of these specific emission sources on air quality in Bishkek. Emissions from domestic heating clearly have a more significant impact on air quality in Bishkek than the emissions from CHP. Traffic emissions were not modeled due to the lack of input data needed for dispersion calculations.

The air pollutant concentrations of priority pollutants such as particulate matter, nitrogen dioxide, sulphur dioxide and carbon monoxide in the Bishkek area are compared to national and international air quality limit values and WHO's health-based guideline values. Most of the pollutant concentrations in the Bishkek area exceed both national and international limit values as well as WHO guidelines.

The analysis identified key emission sources as domestic heating, road traffic, and uncontrolled burning of waste. The report highlights related priority policies targeted to the key emission sources and the Roadmap for implementation of the priority policies and measures provides a policy framework for air quality management.

The structure of the report is divided in two sections. The first section, *Steps Towards Cleaner Air in Bishkek*, presents the key findings of the air quality analysis and modeling, identification of the key sources, and the policy framework for air quality management. The second section, *Scientific Background*, includes in-depth technical details of the air quality analysis and emission inventories, as well as other background information on air quality.

PART I - STEPS TOWARDS CLEANER AIR IN BISHKEK

1 INTRODUCTION

Air pollution means the contamination of the clean, natural ambient air by any chemical or physical substance originating from different emission sources such as motor vehicles, industrial facilities, energy production, and household activities, which all are common sources of air pollution. There are also natural sources of air pollution, such as volcano eruptions, forest and land fires, desert/soil dust and sea salt. Air pollution causes health problems to humans, damage to the environment and materials (such as buildings, monuments etc.). Fine particulates ($PM_{2.5}$ and smaller) are the most harmful pollutant to human health (WHO, 2021). The health effects of the particulates depend on their size and origin. The smaller the particles are, the deeper into the human body they can penetrate and the more damage they can cause. The origin of the particulates defines the chemical composition and toxicity of the particulates. There are two types of particulates: primary and secondary (often referred to as aerosol). Primary particulates are atmospheric particles that are emitted directly into the atmosphere. Secondary aerosols are formed in the atmosphere by chemical reactions on the primary aerosols, such as the creation of sulphuric acid droplets and sulphate particles from sulphur dioxide gas in ambient air. Often, the varying types of aerosols clump together to form hybrid particles of both natural and anthropogenic origin. Technically, an aerosol is the particles and the surrounding gas, aerosol particles are what the actual condensed phase particles are called.

The air pollution situation in Bishkek is severe especially during the wintertime heating periods, occurring from October to March. The Air Quality Index of Bishkek city topped the global air quality index (AQI) rankings in recent years during the heating season. Poor air quality is causing serious health effects, among others i.e., increased cases of child asthma and respiratory disease related morbidity increase. Current governmental air quality management tools, such as the air quality monitoring network including modern, real-time, and reliable monitoring stations and online data, modeling studies, and the emissions inventory, in Bishkek city are insufficient in providing reliable air quality data to support decision-making and to inform citizens about air quality. Therefore, there is a need for enhanced air quality management tools/systems, and more detailed analysis of air quality data to support decision making and preparation of clean air action plans.

In partnership with the United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP) has contracted Finnish Meteorological Institute (FMI) and its subcontractor CHEM-EXP to carry out an Air Quality Study in Bishkek and Supporting the Stakeholders Engagement on Air Pollution Issues. The objective of this air quality study was to analyze the current air quality monitoring and emission inventory data and based on the analysis, to identify the key pollution sources in the Bishkek area and to provide recommendations on strengthening air quality monitoring, and to support air quality management.

This report focuses on presenting the scientific background of air quality in Bishkek based on data analysis of available air quality monitoring data from Bishkek, and using this evidence base, presents a roadmap including the actions and proposed measures towards cleaner air for the city. Data analysed includes the KyrgyzHydromet and US Embassy Air Quality Stations, available air quality sensor data and satellite data. Emission inventories have been used to assess the largest pollution sources, which are likely to have significant impacts on air quality in Bishkek. This study is the first scientific assessment of key emission sources impacting the air quality in the Bishkek area based on the analysis of air quality monitoring data (hourly time series on pollutant concentrations during 2015-2021), emission inventories, local scale dispersion modeling, satellite data and air quality sensor data. Thus, this study and its recommendations are based on the real-time air quality data measured in the Bishkek area, and provide the first evidence-based policy recommendations.

There are many ongoing and upcoming air quality related projects funded by different organizations such as the World Bank (WB), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Asian Development Bank (ADB), Ministry for Foreign Affairs Finland, UNDP, UNEP and UNICEF, and implemented by several local actors in Bishkek, including Public Association "MoveGreen" and others, in the Bishkek area that are supporting in one way or another air quality management in Bishkek city. This is the first comprehensive air quality baseline assessment study about the air quality in Bishkek which is based on many different air quality data sources including the data from air quality monitoring station, low-cost sensors, satellites and emission inventories, and evidence-based recommendations to improve air quality management in the Bishkek area.

Air quality monitoring is one of the cornerstones of air quality management. A baseline assessment including the concentration levels of the different pollutants in the air is essential. Combining monitoring data with emissions inventory data makes it possible to assess and analyze the impact of the different emission sources on air quality. With that information, the decision-makers can make targeted emission reduction plans and policies for improving the air quality. Air quality monitoring is also needed to evaluate the impact and effectiveness of the implemented air pollution prevention actions and measures. Air quality trends can only be seen by long-term air quality monitoring.

However, air quality monitoring itself does not clean the air, and air quality management plans and targeted measures that are effectively implemented are needed. Therefore, well-coordinated and organized air quality management is needed to plan and implement the needed actions and measures.

It is noteworthy that air pollution control and climate change mitigation are closely connected. One of the main sources for air pollution is the burning of fossil fuels and a priority action for climate change mitigation is to reduce or stop the use of fossil fuels. Thus, air pollution prevention actions can also strongly support climate change mitigation and vice versa. Furthermore, investments in climate action often pay off quickly in the short-term through air quality co-benefits via savings in the health sector.

2 HEALTH IMPACTS OF AIR POLLUTANTS

Air pollution is a major environmental health problem affecting everyone both in developed and developing countries. According to the World Health Organization's (WHO) most recent estimations, air pollution kills approximately 7 million people every year, thus it is one of the greatest environmental risks to health (WHO, 2021b). Global Burden of Disease estimates indicate that across 2010-2019, 12–13% of all annual deaths in Kyrgyzstan, were attributed to air pollution, corresponding to between approximately 4100 and 5000 deaths each year (IHME, 2022). The 2019 UNIDO Action Plan for Health and Environment Pollution Issues has shown that air pollution in Kyrgyzstan caused health damage of almost $388 million, or some 6% of the Gross National Income of the Kyrgyz Republic in the year 2015 (Kyrgyz Republic, 2019).

By reducing air pollution levels, countries can reduce the burden of disease such as stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma. There is a strong correlation between health and air pollution: the lower the levels of air pollution, the better the cardiovascular and respiratory health of the population will be, both in the long- and short-term. Exposure to fine particulate matter of 2.5 microns or less in diameter ($PM_{2.5}$), which causes cardiovascular and respiratory disease, and cancers, is the main reason for this mortality rate. The WHO Air Quality Guidelines were updated recently, and the Global Update 2021 provides an assessment of the health effects of air pollution and thresholds for health-harmful pollution levels.

Policies and investments supporting cleaner transport, energy-efficient homes, power generation, industry, and municipal waste management help to reduce the main sources of ambient air pollution. Individuals have very limited opportunities to control air pollution, thus action by local, national, and regional level policymakers working in transport, energy, waste management, urban planning, and agriculture sectors is needed.

WHO has pointed out some examples of successful policies that reduce air pollution in different sectors (WHO, 2021b). Examples of these are listed below.

Industry: introduction of clean technologies that reduce industrial smokestack emissions.

Energy: ensuring access to affordable clean household energy solutions for cooking, heating, and lighting, improved building regulations, insulation and improvements in energy efficiency help to reduce the need/demand in the first place.

Transport: a commonly used framework for policies and measures in the transport sector is "Avoid, Shift, Improve". *"Avoid measures"* include e.g., better city planning or supporting working from home etc. so that journeys are no longer needed. *"Shift measures"* relate to modal "shift", and encourage people to choose cleaner forms of transport. Examples might include various ways of promoting cycling, or the use of public transport rather than private cars. "Avoid" and *"Shift measures"* typically require behavioral change and can be difficult to quantify. *"Improve measures"* are associated with reducing emissions from the same mode of transport e.g., modernizing the vehicle fleet either through sales or retrofitting emissions control equipment on buses or lorries etc. or using low-sulphur fuel.

Urban planning: improving the energy efficiency of buildings and making cities greener and more compact, and thus energy efficient.

Power generation: increased use of low-emissions fuels and renewable combustion-free power sources (such as solar, wind or hydropower); co-generation of heat and power; and distributed energy generation (e.g., mini-grids and rooftop solar power generation). The addition of emissions control equipment can also substantially reduce emissions from power stations.

Municipal and agricultural waste management: strategies for waste reduction, waste separation, recycling and reuse of waste, improved methods of biological waste management such as anaerobic waste digestion to produce biogas and low-cost alternatives to the open incineration of solid waste. Where incineration is unavoidable, then combustion technologies with strict emission controls are critical.

2.1 Priority Pollutants, Definition and Main Sources

WHO defines air pollution as the following:

"Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulphur dioxide. Outdoor and indoor air pollution cause respiratory and other diseases and is an important source of morbidity and mortality" (WHO, 2022a).

The following sections describe the health effects of priority pollutants and are based on WHO data (WHO, 2021a; 2021b; and 2022a).

Particulates (PM_{10} and $PM_{2.5}$)

Particulate matter (PM) poses the most severe health risk of all air pollutants (WHO, 2021). The major components of particulate matter in ambient air are sulphate, nitrates, ammonia, sodium chloride, organic carbon, black carbon, mineral dust, and water. Particulate matter consists of a complex mixture of solid and liquid particles of organic and inorganic substances, such as heavy metals and polycyclic aromatic hydrocarbons suspended in the air. The individual components of PM vary widely in toxicity, and the chemical composition of the particulates depends on their source. The health effects of the particulates depend on their size and origin. Particles with a diameter of 10 microns or less, (≤ PM_{10}) can penetrate and lodge deep inside the lungs, the even more health-damaging particles are those with a diameter of 2.5 microns or less, (≤ $PM_{2.5}$). $PM_{2.5}$ can penetrate the lung barrier and enter the blood system. Chronic exposure to particulate matter contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer. Fine and ultrafine (< 0.1 µm diameter) particles are much more numerous than larger particles despite the larger particles dominating mass concentration measurements.

A threshold for particulate concentrations below which no damage to health is observed has not been identified. The effects of particulate matter on health occur at levels of exposure currently being experienced by most urban and rural populations in both developed and developing countries. Both short-term and long-term exposure to the particulates can cause negative health effects. The health effects of particulate matter are caused after inhaling the particles. There is a close, quantitative relationship between exposure to high concentrations of small particulates (PM_{10} and $PM_{2.5}$) and increased mortality and morbidity, both daily exposure and over time. Conversely, when concentrations of small and fine particulates are reduced, related mortality will also go down, assuming that all other factors remain the same (WHO, 2021a; 2021b; and 2022a).

Currently, the particulate matter concentrations in the Bishkek area are measured only at a couple of air quality measuring stations that meet the requirements of compliance monitoring (equivalent to the reference method). In addition, there are approximately one hundred air quality sensors measuring fine particulate concentrations and streaming data online in real time. Fine particulate annual mean concentration levels in the Bishkek area are around 30 $\mu g/m^3$, which exceed by far all international (EU, US EPA and WHO) and national health based limit and guideline values (the WHO guideline value for annual $PM_{2.5}$ concentration is 5 $\mu g/m^3$) (Please see the limit and guideline values comparison presented in **Table 7**). Therefore, the fine particulates are the priority pollutant to measure and to implement targeted emission measures for. More multi-component air quality measurement stations including fine particulate monitoring and chemical analysis of fine particulates are needed to understand in more detail about the sources impacting the particulate matter concentrations. This is needed for designing targeted measures to reduce $PM_{2.5}$ concentrations. According to this study (based mainly on current available air quality monitoring data), the sulphur-rich fuel used for domestic heating seems to be the main emission source causing high particulate concentration episodes in the wintertime.

Nitrogen Dioxide (NO_2)

Short-term exposure to nitrogen dioxide (NO_2) can result in adverse health effects especially in sensitive population groups for example, pregnant women, particularly above the age of 30, are especially at high risk of losing the unborn fetus, whereas long-term exposure can lead to other serious effects (i.e. reduced lung function) (Liang et al., 2021). Like ozone (O_3), nitrogen dioxide primarily affects the respiratory system. Nitrogen dioxide highly correlates with other pollutants such as particulates. Nitrogen dioxide (NO_2) is also the main source of nitrate aerosols, which form an important fraction of $PM_{2.5}$ and, in the presence of ultraviolet light, of ozone. The major sources of anthropogenic emissions of NO_2 are combustion processes (heating, power generation, and engines in vehicles and ships) (WHO, 2021a; 2021b; and 2022a).

Currently, nitrogen dioxide concentrations in the Bishkek area, available for this study, are measured only at one air quality measuring station that meets the requirements of compliance monitoring (equivalent to the reference method). According to its location and surroundings (**Figure 19**), the KyrgyzHydromet air quality station can be classified as an urban background station, thus the nitrogen dioxide concentrations measured there are likely much lower than in the traffic environment in Bishkek. In addition, there are some air quality sensors measuring nitrogen oxides concentrations streaming results online. Nitrogen dioxide annual mean concentration levels measured in the Bishkek urban background area are around 40 $\mu g/m^3$, which exceeds the WHO guideline values, equals the EU limit value level and is below the US EPA limit value. It is likely that nitrogen dioxide concentrations are clearly higher in the traffic environments compared to that seen at the urban background stations.

Sulphur Dioxide (SO_2)

Sulphur dioxide (SO_2) is a colorless gas with a sharp odor. It is produced from the burning of fossil fuels (coal and oil) and the smelting of mineral ores that contain sulphur. The main anthropogenic source of SO_2 is the burning of sulphur-rich fuel containing fossil fuels for domestic heating, power generation and motor vehicles. SO_2 can affect the respiratory system and lung functions, and cause irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis, and makes people more prone to infections of the respiratory tract.

Currently, health effects are known to be associated with much lower levels of SO_2 than previously believed. Although the causality of the effects of low concentrations of SO_2 is still uncertain, reducing SO_2 concentrations is likely to decrease exposure to co-pollutants. When SO_2 combines with water, it forms sulphuric acid; this is the main component of acid rain which is a cause of deforestation.

Sulphur dioxide concentrations measured in the Bishkek urban background air quality station are very high. Daily mean values exceed 125 µg/m^3 and hourly mean values can exceed 350 µg/m^3 during heating season. Both daily mean and hourly mean values exceed the WHO guideline value, EU and US EPA limit values during wintertime. Currently, sulphur dioxide is measured at the KyrgyzHydromet air quality station (urban background station). However, more measurements would be needed due to the very high concentrations. Sulphur dioxide concentrations seem to be closely linked with the use of sulphur-rich fuel for domestic heating, most likely by private houses.

Ozone (O_3)

Ground level ozone, not be confused with stratospheric ozone (the ozone layer in the upper atmosphere), is formed by the photochemical reaction with sunlight and precursor pollutants such as nitrogen oxides (NO_x) from vehicle and industry emissions, and volatile organic compounds (VOCs) emitted by vehicles, solvents, and industry. As a result, the highest levels of ozone pollution occur during periods of sunny weather. Ozone is also one of the major constituents of photochemical smog. Ozone is a reactive oxidant which can react with a wide range of cellular components and biological materials and may affect tissues of the respiratory tract or lung. Excessive ozone in the air can have a marked effect on human health. It can cause breathing problems, trigger asthma, reduce lung function and cause lung diseases. Currently, there are no ozone measurements carried out in the KyrgyzHydromet monitoring station, nor was there any ozone measurement data available in Kyrgyzstan. Thus, it is highly recommended to start monitoring ozone concentrations as well. Ozone should be measured in rural background areas, urban background, or industrial stations. Traffic stations are not the optimal place to measure ozone concentrations, as ozone is consumed on the chemical processes of nitrogen monoxide to nitrogen oxides and that is why typically ozone concentrations are low near traffic environments.

Carbon Monoxide (CO)

Carbon monoxide is formed from the incompletion combustion of hydrocarbons. Typical sources are traffic and residential heating. In high concentrations carbon monoxide is highly poisonous, limiting the oxygen supply to tissues and inhibiting cellular respiration. Acute carbon monoxide poisoning includes headache, nausea, vomiting, haematemesis, hyperventilation, cardiac arrhythmias, pulmonary oedema, coma, and acute renal failure. Carbon monoxide concentrations in the Bishkek area also peak during wintertime episodes, thus it is recommended to continue measuring carbon monoxide at the KyrgyzHydromet station and establish new air quality stations, where carbon monoxide is measured along with other priority pollutants. It is recommended to measure carbon monoxide in urban background, traffic, and industrial stations.

Persistent Organic Pollutants (POPs)

POPs (Persistent Organic Pollutant) refer to long-range compounds that are highly persistent, toxic and accumulate in organisms. POPs, including polycyclic aromatic hydrocarbons (PAHs), are recognised as being directly toxic to biota. Most of the compounds have been used as various industrial chemicals, flame retardants or pesticides, and some are impurities or are inadvertently generated e.g., in the event of combustion. POPs such as dichlorodiphenyltrichloroethane, polychlorinated biphenyls, dioxins, and furans are the most harmful environmental toxins, as they persist in the environment for a long time and can cause harm to humans and the environment even in low concentrations. Some of these substances are associated with developmental and reproductive disorders observed in animals and may affect humans in the same way. The long-term interactions of the substances are not yet known.

Incomplete combustion of fuels releases polycyclic aromatic hydrocarbons, or PAHs, into the air. PAHs are released into the air during all combustion of organic matter, but the most significant sources in urban air are the emissions from domestic burning as it is not often very efficient and clean, and road transport exhaust. Some industries are also sources of PAHs. PAHs are bound to airborne particles ($PM_{2.5}$ and PM_{10}). The best known and studied PAH compound is benzo(a)pyrene (BaP) and is used as a representative of PAHs. In the European Union, the annual average concentration of BaP in ambient air must not exceed the target value of 1 nanogram per cubic meter (ng/m^3). Currently, there are no POPs measured in the Bishkek area. It would be highly recommended to measure benzo(a)pyrene for example over a one-year period at the KyrgyzHydromet urban background air quality station. Benzo(a)pyrene is measured on particulates, by filter sampling and chemical analysis in the laboratory. The analysis process requires special expertise and laboratory equipment, but it is also possible to send the samples to be analyzed to a laboratory specialized in the analysis of PAHs. It is likely that benzo(a)pyrene concentrations are very high in the Bishkek area due to the common use of sulphur-rich coal for domestic heating in old traditional solid fuel-fired stoves (World Bank, 2020).

2.2 Updated Global Air Quality Guidelines from World Health Organization

The World Health Organization (WHO) released updated global air quality guidelines in September 2021 (WHO, 2021a). **Table 1** shows the new recommendations for $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO concentrations. The air quality guidelines which remained valid are represented in **Table 2.** Since WHO's last update of global air quality guidelines in 2005, there has been a great increase in scientific knowledge about the health effects resulting from exposure to air pollution.

In addition to guideline values, the WHO Global air quality guidelines provide interim targets for concentrations of PM_{10} and $PM_{2.5}$ which are aimed at promoting a gradual shift from high to lower concentrations. By achieving these interim targets, significant reductions in risks for acute and chronic health effects from air pollution can be expected. However, according to WHO, achieving the guideline values should be the ultimate objective. For countries where an immediate transition to the guideline values is not feasible due to financial, capacity, and other constraints, the interim target values are useful goals for significantly reducing the health burden from air pollution, and the enhanced air quality management that comes with reaching these will place the country on a path for successfully achieving the guideline values in the mid-term.

In low- and middle-income countries, exposure to pollutants in and around homes from the household combustion of polluting fuels on open fires or traditional stoves for cooking, heating, and lighting further increases the risk for air pollution-related diseases, including acute lower respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease, and lung cancer. Women and children are more exposed to indoor air pollution as they spend more time at home and are more involved in the activities of household combustion for example cooking.

Table 1 New updated air quality guidelines from WHO (WHO, 2021a).

Pollutant	Averaging time	Interim target				New AQ guideline
		1	2	3	4	
$PM_{2.5}$ (µg/m^3)	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10} (µg/m^3)	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3 (µg/m^3)	Peak season[b]	100	70	-	-	60
	8-hour[a]	160	120	-	-	100
NO_2 (µg/m^3)	Annual	40	30	20	-	10
	24-hour[a]	120	50	-	-	25
SO_2 (µg/m^3)	24-hour[a]	125	50	-	-	40
CO (mg/m^3)	24-hour[a]	7	-	-	-	4

[a] 99^{th} percentile(i.e. 3-4 exceedance days per year).

[b]Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

Table 2 WHO air quality guidelines which remained valid (since 2005) (WHO, 2021a).

Pollutant	Averaging time	AQ guideline that remained valid
NO_2 (µg/m^3)	1-hour	200
SO_2 (µg/m^3)	10-minute	500
CO (mg/m^3)	8-hour	10
	1-hour	35
	15-minute	100

2.3 Gender Aspect of Air Pollution

Previous studies have shown that exposure to air pollution and the resulting health risk could depend on socioeconomic factors like gender, social class, and ethnicity. Women can be particularly vulnerable to air pollution due to traditional gender roles, lower salaries, motherhood, and cultural norms. A major source of indoor air pollution is cooking using solid fuels (for example wood, crop wastes, charcoal, and coal) and kerosene in open fires and inefficient stoves. The constrained volumes indoors lead to much higher concentrations of pollutants and thus spending more time indoors gives one longer exposure time but also a higher exposure dose of pollution. Epidemiological studies have shown that miscarriage, preterm birth, and low birth weight are related to high levels of air pollution exposure (WHO, 2022b).

Air pollution is one of the leading risks to child health, accounting for almost 10 per cent of deaths in children under five years old. Household air pollution from cooking and outdoor air pollution cause more than 50 per cent of acute lower respiratory infections in children under five years old in low- and middle-income countries. Exposure to air pollution affects children's neurodevelopment which can lead to lower cognitive, mental and motor development as well as triggering of cancer or childhood asthma (WHO, 2022b).

Therefore, any interventions to solve the issue of air pollution should consider the gender dimension of exposure and health impacts of pollutants. This will in the long run reduce gender inequalities exacerbated by air pollution. For instance, in the case of designing and developing clean energy technologies as an alternative measure for indoor pollution, women should be considered as a major stakeholder group since they are more exposed to indoor pollution. This will solve the indoor pollution problem while simultaneously reducing the time spent by women on gender related activities like cooking using solid fuels.

3 KEY FINDINGS

3.1 Air Pollution in Bishkek

Air pollution in Bishkek is severe. Pollutant concentrations are very high, exceeding the national and international health-based limit values and WHO guidelines throughout the year and especially during the wintertime heating period. Severe wintertime pollution episodes are mainly caused by burning poor quality sulphur-rich coal for residential heating in private houses, combined with the local meteorological conditions that lead to the poor mixing of air. The high traffic volume in Bishkek is another major contributor to air pollution.

Results from long-term, multicomponent air quality monitoring at the KyrgyzHydromet automatic monitoring station suggest that the severe wintertime pollution episodes are caused by widespread use of sulphur-rich coal for residential heating in homes not connected to the CHP heating grid. The results also strongly suggest that it is not a question of one or several point sources but many small-scale emission sources, such as residential heating, occurring throughout the city.

The main emission sources in the Bishkek area are energy production (including the Bishkek CHP plant, district heating plants and residential heating) and road traffic-related emissions. However, emission volumes do not directly indicate the impact of the emission source on the air quality. For example, emission sources close to breathing height, such as traffic and household heating and burning activities, can have a bigger impact on air quality than larger emission amounts released from high stacks. Modeling studies suggest that the impact of the CHP station emissions on ground-level pollution concentrations is less important than other sources.

Exposure to fine particulate matter, especially particles smaller than 2.5 micrometers ($PM_{2.5}$), poses the most severe health risk of all air pollutants. Policies and investments supporting cleaner energy production, energy-efficient homes, and industry and municipal waste management, help to reduce ambient air pollution and are urgently needed in Bishkek.

3.2 Key Emission Sources

The key emission sources impacting the air quality in Bishkek have been identified mainly through analysis of air quality monitoring data from the KyrgyzHydromet automatic station and the emissions inventory data. The KyrgyzHydromet station is the only multicomponent air quality station with data available for this study.

Additional information from satellite-based observations and air quality sensors have been used as supplementary data in the assessment. Also, the dispersion modeling tool UDM-FMI has been used to demonstrate the impact of certain emission sources on air quality. The results of dispersion modeling calculations are indicative as the input data for the model has been calculated based on the available data sources. Technical and emissions data characterizing the CHP plant were needed for dispersion modeling, but not all data were available, so it was necessary to make estimates and use expert judgment.

3.2.1 Impact of Emissions from CHP on Air Quality in Bishkek

The Bishkek coal-fired combined heat and power (CHP) station is the main energy production plant in the Bishkek area (**Figure 1**). The plant currently produces 910 MW of electricity and generates thermal energy for hot water and heating. The Bishkek CHP plant is currently the largest electricity provider in the north of Kyrgyzstan (GEM, 2022).

According to the emission inventory done for this study, it produced approximately 55 per cent of Bishkek's total SO_2 emissions, less than 10 per cent of Bishkek's NO_X emissions and 5 per cent of Bishkek's $PM_{2.5}$ emissions in 2021. Emissions from the CHP plant are released into the air through high stacks (estimated heights of the stacks of 60–160 meters, with this figure possibly an underestimation). Data on stack heights were requested from CHP, but it was not possible to obtain this information for the modeling. Thus, assumptions and expert estimates were made as necessary. Subsequent information obtained suggests that the height of the functioning stacks are 150m, 180m, and 300m. The results of this modeling should be considered indicative, and it is likely that CHP emissions have an even smaller impact on ground-level emissions than in the modeling shown here.

The CHP-plant mostly uses domestic coal but in 2021, a Kazakhstani company won the tender for supplying fuel from Kazakhstan, and imports approximately 650 thousand tons of coal from the Karazhyra field. About a million tons of coal used by the plant still come from the Kara-Keche coal mine in Kyrgyzstan, while the additional 650 kilotons are expected to come from the Kazazhyra field. According to the International Energy Agency, the Bishkek CHP plant requires 2.5 million tonnes of coal per year (GEM, 2022; IEA, 2020).

Figure 1 Bishkek coal-fired combined heating and power (CHP) plant. Photo by Romain Marat (2021).

The air quality impact of the exhaust gasses from the Bishkek CHP plant was analyzed using a mathematical atmospheric Gaussian urban dispersion model UDM-FMI developed by the Finnish Meteorological Institute (FMI) (Karppinen et al., 1998; Karppinen, 2001). The urban scale modeling system is able to allow for the various local-scale effects, for instance, the influence of buildings and obstacles, downwash phenomena and plume rise, together with chemical transformation and deposition (e.g., Kukkonen et al., 1997).

Concentrations of sulphur dioxide, nitrogen dioxides and particulate matter were calculated by using the dispersion model for the year 2021. The meteorological data representing plant location used in the simulations was extracted from the database of FMI which includes international weather observations shared via World Meteorological Organization's (WMO) Global Telecommunications Systems. The meteorological data used in the modeling is described in more detail in **Chapter 5.2.** The technical input data of the source term and the emissions were estimated based on the available data sources and calculated by Aether Ltd. The input data used in the modeling is presented in **Table 3.** The estimates and assumptions were made conservatively to avoid being too optimistic in terms of air pollution impacts. The emission and technical data were requested directly from the Bishkek CHP plant, but it was not possible to get the input data needed for the modeling. Thus, assumptions and expert estimates were made as necessary, and the results of the dispersion modeling calculation should therefore be considered indicative.

Calculated concentrations were compared against the WHO guidelines and concentrations measured at the air quality monitoring station operated by KyrgyzHydromet (**Figure 5 and 6**). The aim of the dispersion modeling case study was to demonstrate the impact of the CHP station on ground-level air quality. The results of dispersion modeling calculations are presented in **Figures 2-4**.

Table 3 Emission data (calculated) and source characteristics (estimated and calculated based on applicable data available) used in the dispersion modeling. Hours of operations are shown in hours/year (h/a). The emissions are shown in tons/year (t/a).

Emission source	Hours of operation (h/a)	Stack height (m)	Exhaust gas, Stack exit Temp (°C)	SO_2 (t/a)	NO_x (t/a)	$PM_{2.5}$ (t/a)
stack 1	8016	160	200	4 388	2 206	70
stack 2	4368	80	200	2 391	1 202	38
stack 3	4368	60	200	2 391	1 202	38
Total				**9 170**	**4 610**	**146**

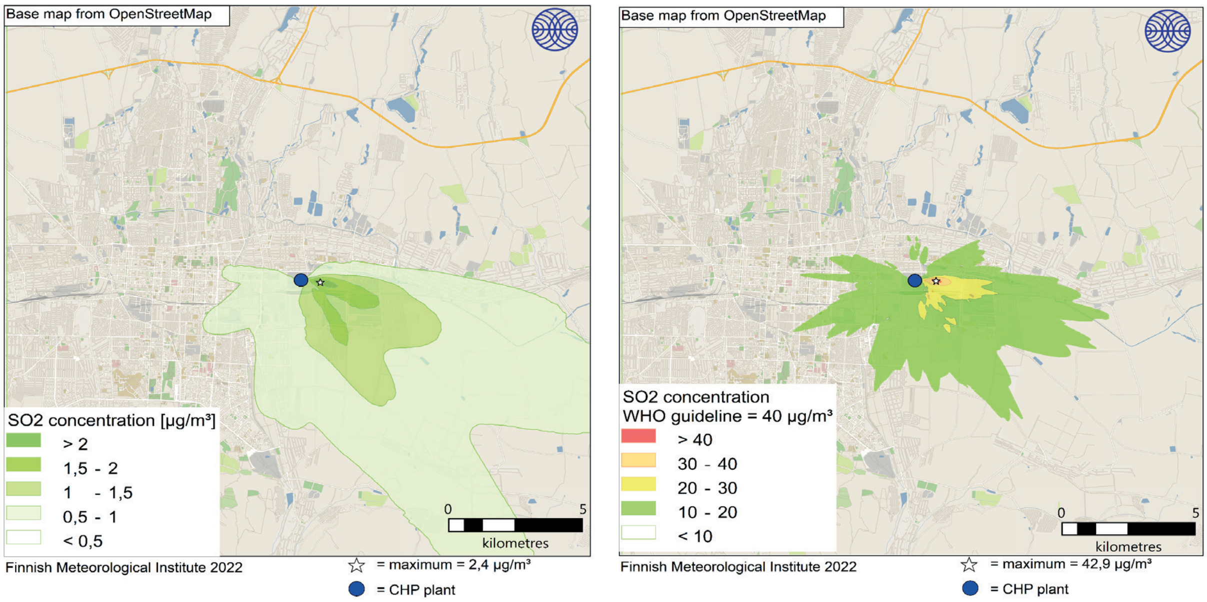


Figure 2 Sulphur dioxide (SO_2) annual average concentration (µg/m^3) (on the left) and daily mean concentration (µg/m^3) (on the right) caused by the Bishkek CHP station, based on calculated emission inventory data for 2021.

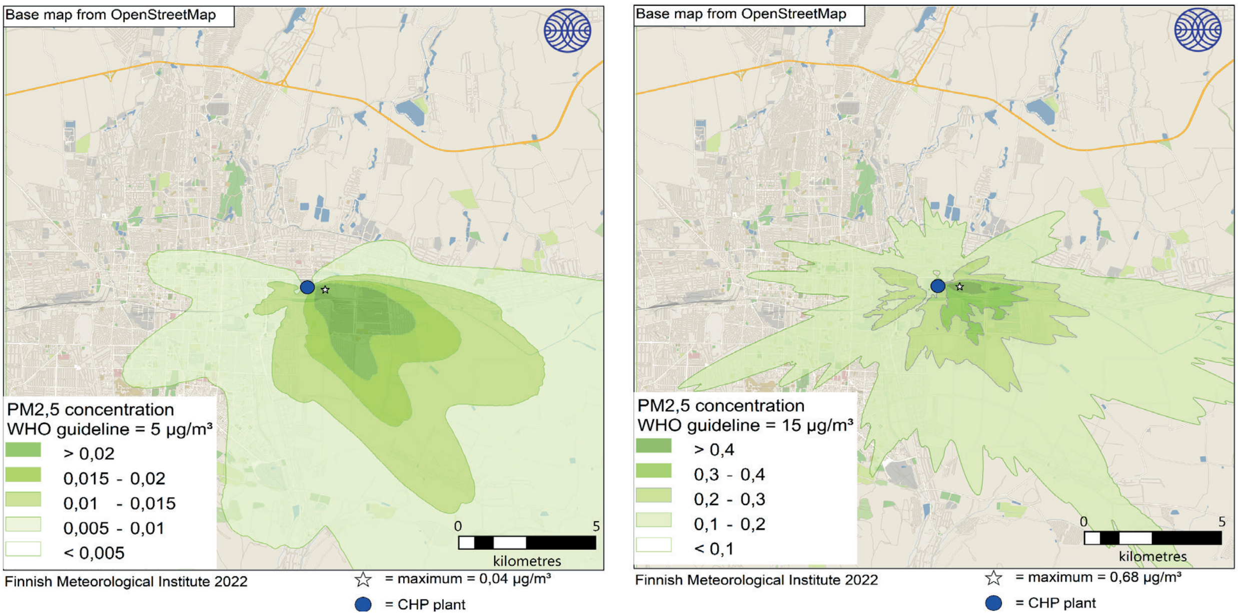


Figure 3 Fine particulate matter ($PM_{2.5}$) annual average concentration (µg/m^3) (on the left) and daily mean concentration (µg/m^3) (on the right) caused by the Bishkek CHP station, based on calculated emission inventory data for 2021.

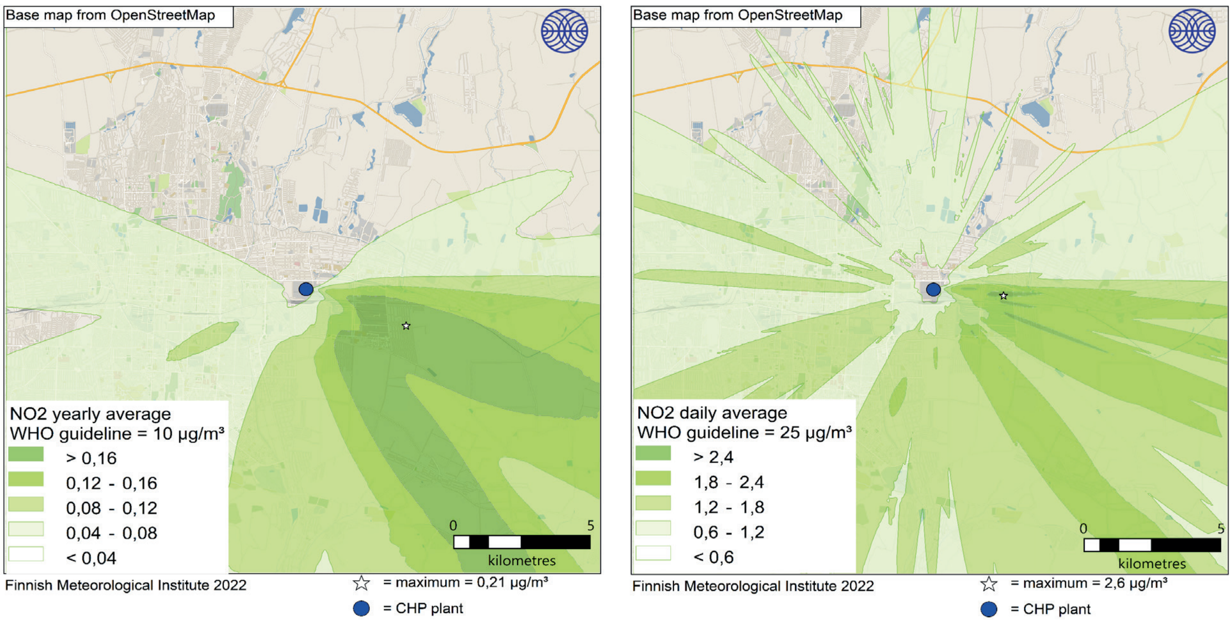


Figure 4 Nitrogen dioxide (NO_2) annual average concentration (µg/m^3) (on the left) and daily mean concentration (µg/m^3) (on the right) caused by the Bishkek CHP station, based on calculated emission inventory data for 2021.

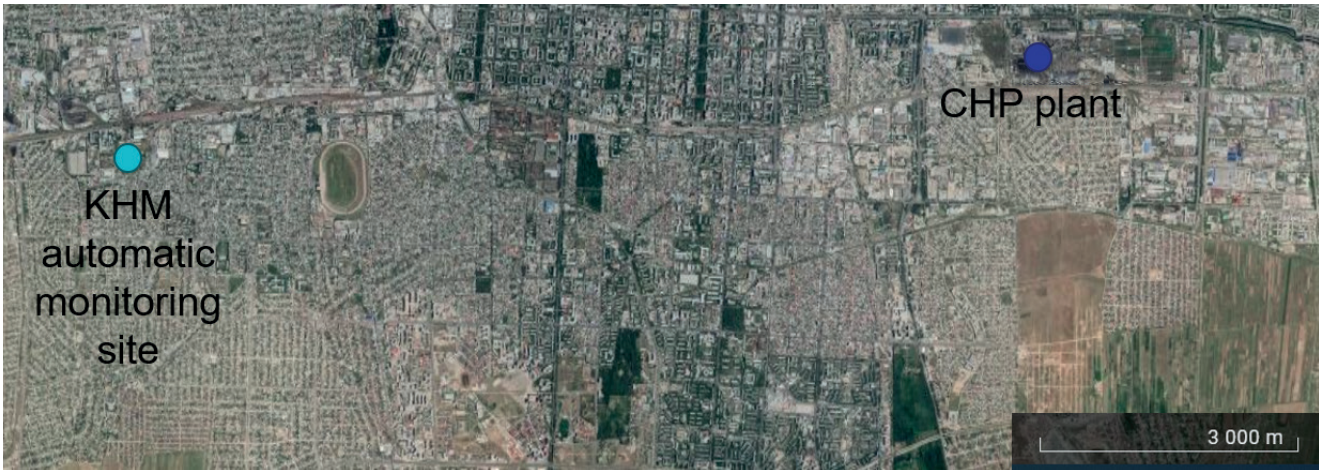


Figure 5 The location of the KyrgyzHydromet Air Quality Monitoring station and Bishkek CHP plant. The distance between the air Quality monitoring station and CHP plant is approximately 10 kilometers.

According to dispersion modeling calculation results, the impact of the Bishkek CHP station air emissions on ground level concentrations are clear compared to the total SO_2 concentrations measured at the KyrgyzHydromet air quality monitoring station. The maximum modeled annual mean concentration of SO_2 produced by the CHP plant was 2.4 μg/m^3, while the measured maximum annual mean value of SO_2 concentration at the KyrgyzHydromet station was 24 μg/m^3 (**Table 4**). Thus, the magnitude of the CHP plant emission contribution to the ground level concentrations can be estimated to be around 10 per cent of the ground level concentrations. However, the KyrgyzHydromet station is located over 8 kilometers away from the Bishkek CHP plant, thus the maximum modeled concentrations are not fully comparable with the measured values, although they give an indication about the magnitude of the impact of CHP emissions on ground level concentrations. The maximum modeled concentration was located nearby the CHP plant. According to the emissions inventory, the Bishkek CHP plant is a major source of SO_2 emissions, producing over 50 per cent (ca. 10 tonnes) of the total annual SO_2 emissions (ca. 22 tonnes) in the Bishkek area (**Chapter 8.4.4**). Residential combustion is the second largest source of SO_2 in the emissions inventory but is expected to make a proportionately larger contribution to ambient concentrations because the emissions are released much closer to ground level.

The impact of the CHP station emissions on the ambient air concentrations of the other pollutants, particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2), is clearly less than that of SO_2 (**Table 4)**.

Table 4 The maximum modeled annual mean sulphur dioxide concentrations (µg/m^3) caused by the Bishkek CHP plant compared with the highest annual average SO_2 concentrations measured at the KyrgyzHydromet station during 2018–2020. There was no ozone data available for Bishkek, so the ozone data used in the model is from Finland. Ozone has a great impact on the NO_2 results, so to highlight the uncertainty in the results, NO_2 concentrations are coloured with gray color.

	Modeled maximum yearly average concentration [µg/m^3	Measured maximum yearly average concentration [µg/m^3]	Indicative Contribution of CHP plant to measured concentration*
SO_2	2.4	24	10 %
$PM_{2.5}$	0.04	29	< 1 %
PM_{10}	0.04	100	< 1 %
NO_2	0.21	40	< 1%

*The KyrgyzHydromet station is located over 8 kilometers away from the Bishkek CHP plant, thus the maximum modeled concentrations are not fully comparable with the measured values, but they give indication about the magnitude of the CHP emission impact to the ground level concentrations.

One of the main reasons for the minor impact of CHP station emissions on ground level concentrations despite the high emission volumes are the high stacks which enable effective dispersion and dilution of emissions. In meteorological situations with low mixing height (poor mixing conditions, creating an unfavorable situation for air quality) the stacks are often above the mixing layer and emissions are dispersed with upper atmospheric winds and therefore do not contribute at all to the atmospheric concentrations at ground level. In those cases, the impact of the emissions on the ground level concentrations nearby the plant are very low.

The main conclusion of the dispersion modeling of the CHP station case study is that the Bishkek CHP plant is not the main emission source impacting ground-level pollutant (SO_2, $PM_{2.5}$ and NO_2) concentrations in the Bishkek area. Thus, even though it is recommended in the long run to reduce or stop the use of fossil fuels by switching to renewable energy sources for climate mitigation purposes, which also has a positive impact on the air quality, it is not the priority action to improve the air quality in Bishkek in the short term. According to this air quality assessment study, there are more significant emission sources than CHP plant, notably from domestic heating that uses sulphur-rich fossil fuel. CHP has a smaller impact on air quality and particularly on the priority pollutants (fine particulate matter and sulphur dioxide) concentrations in the Bishkek area due to higher release height, efficiency of combustion and control equipment installed.

However, in case the use of fossil fuels is a necessity at the moment and near future, it is clearly a better option to produce heat and electricity by using the coal in the CHP station than in traditional solid-fuel stoves by private houses. While a rapid shift away from coal and other fossil fuels is crucial, note that conditions for burning coal in the CHP station are significantly more efficient with less of an impact on air quality than fuel-burning in solid fuel stoves in private houses. In the CHP station the fuel-burning conditions are better controlled and optimized, there are possibilities to use emission control and abatement technologies, and emissions are released into the air through high stacks. All these minimize the impact of the CHP station's emission on ground-level concentrations compared to coal burning in private houses.

3.2.2 Impact of Transport Emissions on Bishkek Air Quality

According to the emission inventories (**Chapter 8**), road transport is the greatest source of nitrogen oxides (NO_X) and a considerable source also of fine particulates ($PM_{2.5}$) emissions in the Bishkek area. Traffic emissions are also released into the air near ground level and that is one reason why they typically have a significant impact on air quality.

The emissions inventory calculations allow for engine technologies to be taken into account for e.g. cars, vans, lorries, and buses. But it has not been possible to obtain detailed information on cars and other vehicles that are in use for this study. Vehicles equipped with emissions control technologies can emit an order of magnitude less air pollution than those without, so it is important to be able to characterise the vehicles being used. This is complicated by the fact that vehicles in Bishkek often have their emissions control equipment removed.

It has also not been possible to obtain official data about activity levels. Estimates have been made of the total fuel used by various road vehicles in Bishkek, but distribution of e.g. diesel between cars, vans and lorries has had to be estimated. More work is needed to obtain better data, and prepare emission maps of the road network to show where in Bishkek the largest emissions arise.

Currently there are no automated air quality stations located near busy traffic environments in Bishkek city, thus it is not possible to study in detail the impact of traffic emissions on air quality in the city center and nearby the largest roads. It is likely that nearby main roads and in areas experiencing heavy traffic, the traffic-related air pollutant concentrations are much higher than in the urban background areas where the KyrgyzHydromet air quality station is located.

Bishkek's growing population and increased car ownership has brought along an increase in traffic, traffic emissions and elevated NO_2 concentrations. Solving this kind of local-scale air quality problem requires not only reduction of tailpipe emissions but also difficult and expensive structural changes, such as major improvements and investments in public transportation, too. A solid understanding of the seriousness of the problem is needed before making the difficult decisions about measures needed to improve the air quality.

3.2.3 Impact of Domestic Heating Emissions (non CHP-related) on Bishkek Air Quality

According to the analysis of available air quality monitoring data from KyrgyzHydromet station, the severe wintertime pollution episodes are caused by using sulphur-rich coal for residential heating. The analysis also strongly suggests that it is not a question of one or a few point sources but of fugitive small-scale emission sources like residential heating occurring throughout the city.

A strong positive correlation between CO, NO_X, SO_2, $PM_{2.5}$ and PM_1 was detected (The correlation analysis has been presented in more detail in **Chapter 6.1, Figure 27**). These compounds most likely are emitted from combustion sources. PM_{10} is weakly correlated and TSP not at all with these "combustion pollutants". TSP is predominantly dust and so is the coarse fraction of PM_{10}, which explains the weakened correlation with the combustion pollutants. The fine fraction ($PM_{2.5}$ and PM_1) of PM_{10}, though, results in a reasonable correlation with the other combustion pollutants.

CO, NO_X, SO_2, $PM_{2.5}$ and PM_1 are negatively correlated with wind speed, i.e. concentrations increase when wind speed decreases, which suggests that the pollution experienced in Bishkek is caused by local emissions, and thermal inversions during nighttime and wintertime as well as thermal inversions caused by the proximity of mountains.

SO_2, $PM_{2.5}$ and PM_1 concentrations are strongly negatively correlated with temperature (concentrations increase when temperature decreases) i.e., when temperatures are very cold, concentrations of SO_2, $PM_{2.5}$ and PM_1 are highest. This strongly suggests that the high concentrations of SO_2, $PM_{2.5}$ and PM_1 result from emissions from small-scale heating emissions with solid fuels. Another reason causing this may also be due to the increase in atmospheric stability and poor mixing conditions with decrease in temperature. These results also help to identify the main source of emissions based on known characteristics of emissions from various fuel types.

Thus, as SO_2 concentrations are also strongly correlating with other combustion pollutants measured in KyrgyzHydromet station, it seems that coal (with high sulphur content) combustion has a role in the severe wintertime pollution episodes in Bishkek. Wood combustion emissions are rich in fine PM (PM_1 and $PM_{2.5}$) but carry no $SO_{2,}$ and wood is not the main source of fuel for residential heating in the city.

The emissions inventory (presented in **Chapter 8** in this report) indicates that the main emission sources for air pollution are energy production (CHP plant and residential heating), and road traffic related emissions. However, emission volumes do not directly describe the impact of the emissions source on air quality (emissions volumes do not correlate directly with ground-level pollution concentrations).

The air quality impact of domestic heating emissions (not related to the CHP or district heating) was also assessed using the mathematical atmospheric dispersion model UDM-FMI (Karppinen et al., 1998; Karppinen, 2001). Concentrations of sulphur dioxide, nitrogen dioxides and particulate matter were calculated by using the dispersion model in the theoretical case study for an approximately 1km x 1km suburban area in Bishkek including 1 480 houses (the number of houses was estimated based on the assumption that each house has an area about 750m^2). It was assumed that houses in the case study area are not on the CHP or district heating networks and are therefore not provided with hot water for heating. Each house was assumed to have the same emissions related to the heating. These heating related emissions were assumed to be emitted during the heating season from October until March. Emissions were calculated based on the weighted average of three different types of conventional stoves presented below. The emissions were estimated based on the available data sources and calculated by Aether Ltd. The estimates and assumptions that are used to calculate the emissions that are used as input data for modeling were done conservatively to avoid being too optimistic in terms of air pollution. The meteorological data used in the modeling is described in more detail in **Chapter 5.2.**

- **Conventional coal stoves**

  There are three different types of conventional coal stove (“traditional”, “burzhuika” and “kantromarka heating wall”), but for the purposes of this study a weighted average was used.

- **Small coal boilers**

  This includes “automated”, “simple” and “artisanal” coal boilers. These were also calculated as a weighted average.

- **Gas, wood and municipal solid waste**

  There is some use of gas indicated for the residential sector that is not covered in district heating. It is not clear whether this is gas mains or bottled gas. The methodology used in the inventory means that it is not possible to estimate the emissions from gas use for one household.

Table 5 Emission estimates for conventional stoves and small coal boilers in Bishkek.

	Coal consumption	NO_x	SO_2	$PM_{2.5}$
	t/year	kg	kg	kg
Conventional stove	2.44	5.86	58.6	28.13
Small coal boiler (<=50 kWth)	3.22	12.21	77.3	23.19
Sum	5.66	18.07	135.9	51.32

Proportions of the above categories in the study area

The proportion of houses across the three categories above will very much depend on the location. A World Bank study (World Bank, 2015) indicates the following mixture of appliances in households:

Table 6 Share of appliances in households in Bishkek.

Electric heater/boiler	11 %
Gas heater/boiler	14 %
Conventional **coal** stove	27 %
Small **coal** boiler	48 %

A theoretical residential area located away from the city center which is supposedly occupied by residents of lower-than-average income was selected for this case study. The area around the KyrgyzHydromet air quality monitoring station was not selected as the closest residential buildings are located hundreds of meters away from the station. The assumption is that the houses in the selected case study area are using only conventional coal stoves and small coal boilers. Calculated concentrations ($PM_{2.5}$ and SO_2) for the theoretical case study of domestic heating emissions representing the suburban area of Bishkek with approximately 1 500 private houses that use solid fuel (coal) for the heating were very high. The maximum annual average of SO_2 (over 200 µg/m^3) and for $PM_{2.5}$ (approximately 90 µg/m^3) concentrations located in the studied residential area (**Figures 6 and 7**). The dispersion modeling case study is indicative and demonstrative, and it includes high uncertainties due to the many assumptions made in calculating the emissions. However, even with high uncertainty, the dispersion calculation results agree well with the conclusions made based on the air quality monitoring data that domestic heating emissions have significant impact on the SO_2 and $PM_{2.5}$ concentrations in urban background (suburban areas) of Bishkek. Also, the low-cost air quality sensors in different suburban areas in Bishkek indicate very high daily mean $PM_{2.5}$ concentration peaks during the heating season (**Chapter 6.4, Figure 32**). Therefore, domestic heating emissions should be considered as a priority emission source for emission reductions.

Nitrogen dioxide (NO_2) concentrations caused by domesting heating in this case study were low compared to the air quality impact of sulphur dioxide and fine particulate emissions (**Figure 8**). Due to the lack of local background ozone measurement data that is needed in the modeling, the uncertainty of NO_2 modeling was also considerably high. However, it is likely that highest NO_2 concentrations in Bishkek will be found from the traffic environments instead of the suburban areas. According to the emission inventories (**Chapter 8**) road traffic is by far the main emission source for nitrogen oxides.

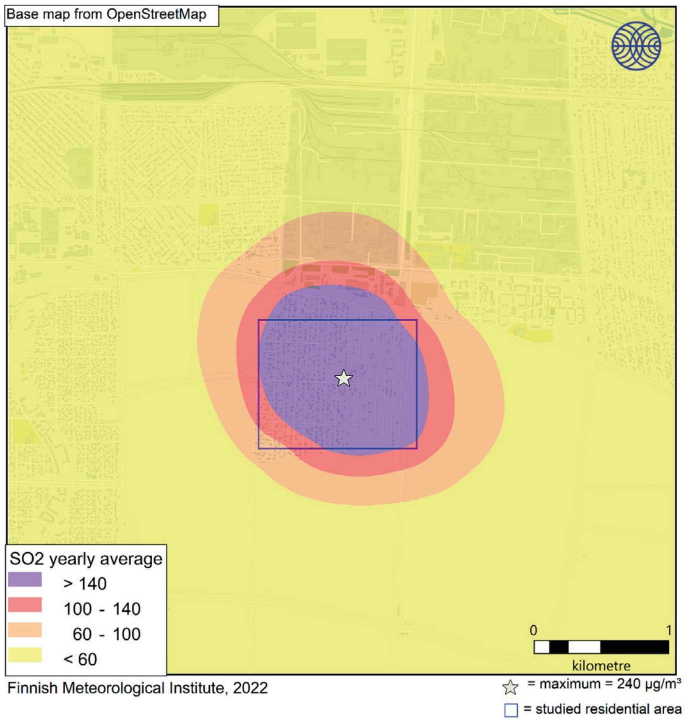


Figure 6 Sulphur dioxide (SO_2) annual average concentration (µg/m^3) caused by the Domestic Heating Emissions (non CHP-related), based on calculated emission inventory data for theoretical area of 1km x 1km residential area with 1 480 homes (blue square in the Figure).

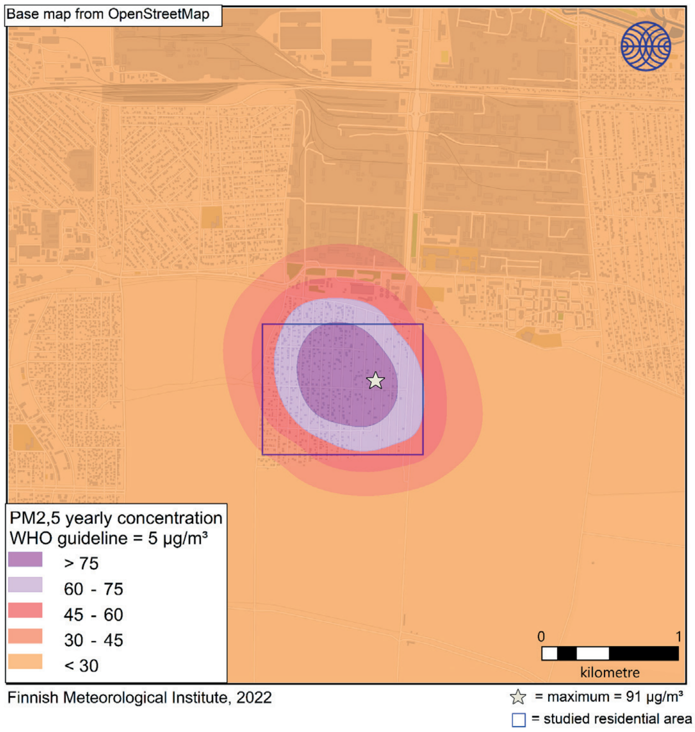


Figure 7 Fine particulate matter ($PM_{2.5}$) annual average concentration (µg/m^3) by the Domestic Heating Emissions (non CHP-related), based on calculated emission inventory data for theoretical area of 1km x 1km residential area with 1 480 homes (blue square in the Figure).

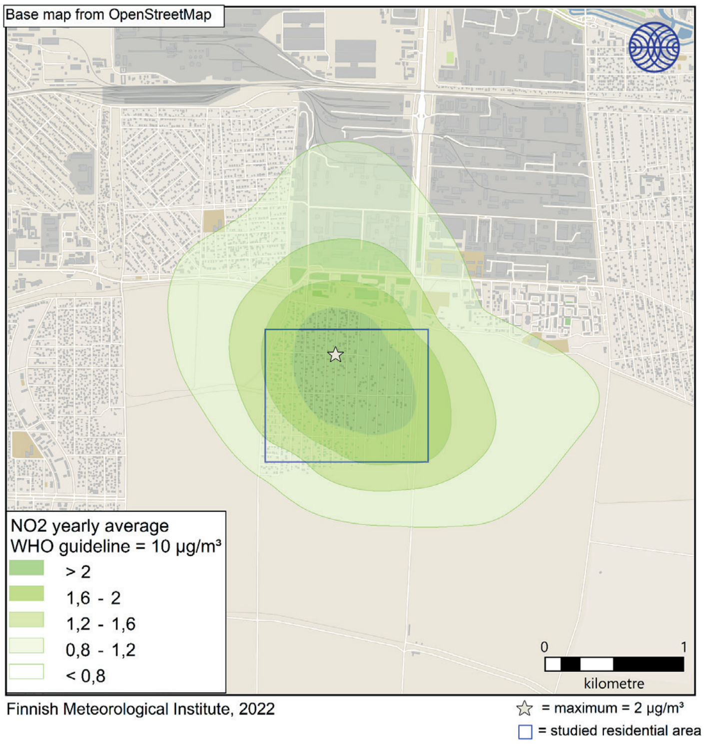


Figure 8 Nitrogen dioxide (NO_2) annual average concentration (µg/m³) caused by the Domestic Heating Emissions (non-CHP related), based on calculated emission inventory data for theoretical area of 1km x 1km residential area with 1 480 homes (blue square in the Figure).

4 POLICY FRAMEWORK FOR AIR QUALITY MANAGEMENT

4.1 Current Legislation

Current legislation and regulations for air quality monitoring rely on manual 20-minute sample collection with defined maximum allowed concentration levels of pollutants. In this regulation the highest permitted single observation value is set for each pollutant and the concentrations of the twenty minutes samples are compared to this value. Another maximum permissible concentration level is set for the daily mean, which is calculated based on the 20-minute manual sampling. **Table 7** summarizes the major international air quality standards, (from the European Union, guideline values of WHO, and AQ (primary) standards for health protection in the US) together with Kyrgyzstan's national standards.

It is strongly recommended that Kyrgyzstan reforms the national air quality legislation governing the monitoring of primary pollutants, so that it is based on modern air quality measurement technology that is mostly based on automatic continuous measurements instead of outdated manual sampling.

Table 7 Air quality limit values of European Union, guideline values of WHO, and AQ (primary) standards for health protection in the US and Kyrgyz national AQ standards for selected pollutants.

		EU	Comments	WHO	Comments	US EPA	Comments	Kyrgyzstan
Pollutant	Averaging period	Limit value μg/m³	Not to be exceeded more than	Guideline Value μg/m³	Not to be exceeded more than	Standard for health protection	Not to be exceeded more than *averaged over three years	Maximum permissible concentration μg/m³
SO_2	Hourly	350	24 times/yr			75 ppb (~200 μg/m³)	*99th percentile of daily 1h max	500[1]
	Daily	125	3 times/yr	40	3-4 times/yr			50
NO_2	Hourly	200	18 times/yr	200		100 ppb (~200 μg/m³)	*98th percentile of daily 1h max	85[1]
	Annual	40		10		53 ppb (~100 μg/m³)		
	Daily			25	3-4 times/yr			40
PM_{10}	Hourly							300[1]
	Daily	50	35 times/yr	45[2]	3-4 times/yr	150 μg/m³	*1 times/yr	60
	Annual	40		15				
$PM_{2.5}$	Hourly							160[1]
	Daily			15[2]	3-4 times/yr	35 μg/m³	*98th percentile	35
	Annual	25		5		12 μg/m³		
CO	Hourly			35000		35 ppm (~40 000 μg/m³)	1 times/yr	5000[1]
	8h average	10000		10000		9 ppm (~10 000 μg/m³)		
	Daily			4000[2]	3-4 times/yr			3000

[1] maximum single value.

[2] 99th percentile (i.e. 3-4 exceedance days per year).

4.2 Current Plan to Improve the Environmental Situation in the City of Bishkek

The current Plan of Comprehensive Measures to Improve the Environmental Situation in the City of Bishkek and Sokuluk, Alamudun districts of Chui region for 2021-2023 has been approved in May 2021. It includes in total 43 actions and measures under eight thematic areas listed below. The implementation timeframe of these actions and measures is in most cases 2021-2023. Thus, it is a large and ambitious plan including a wide range of topics, priority areas with mixed actions and measures. Given a three-year timescale for the implementation for the planned measures and to achieve the expected result is very short for implementation of many of the actions considering the resources needed for implementing all of them.

Below are the eight thematic areas of current plan to improve environmental situation:

1. Planning, urban planning and design
2. Preservation and development of green areas
3. Solid waste management
4. Heat supply and heating
5. Public transport and urban mobility
6. Individual transport
7. Air pollution monitoring, information
8. Control activity

As the current plan is already halfway through its implementation time (2021-2023), it is recommended to start soon to plan and prepare a new plan. It is important to also critically assess how the implementation of the current plan is ongoing and to learn of the possible challenges while preparing the new plan from 2024 onwards.

It is recommended to prepare a separate plan that is targeted and focused only for the improvement of the air quality situation in Bishkek. By focusing on air quality improvement only, it is more manageable, easier to steer and to set priority areas, involve and engage responsible organisations, manage the funding for the actions and plans, and to follow-up and assess the impact and effectiveness of the actions implemented.

An air quality improvement plan means in practice an air pollution prevention and control plan, as emission reductions for air pollution are needed to improve the air quality situation. It is important to have high level (Government, Ministers) commitment and ownership of air quality improvement objectives and plans as the practical work requires considerable investments and financial support as well as development of the legislative tool and policies. A strong communication campaign should follow both development and implementation of the Air Quality improvement plan.

It is important to set achievable goals for the selected priority areas and to have a realistic time schedule planned for the implementation of identified and selected measures. Often, implementing actions, for example building up new regulations or legislation, can take up to five years, and the impact is seen after the new regulation and legislation comes into force. Long implementation times need close steering and supervision so that the process proceeds as planned. There is also the need to establish a cross-ministerial executive steering board that follows closely on the process and effectiveness of the implementation process.

However, even though the air quality improvement is long-term up to a five to ten-year timescale, it is very important to start implementing the emission reduction actions and the improvement of the air quality monitoring network and capacities as soon as possible. Actions can be done step-by-step, by implementing actions and measures one by one.

4.3 Identified Key Emission Sources and Related Priority Policies

Bishkek's air quality and identified key emission sources have been presented in **Chapter 3** and **Chapter 6**. Based on the analysis of the available air quality data, developed emission inventory data and some dispersion modeling calculation case studies, there have been three priority key emission sources identified. In order of their contribution to air pollution in Bishkek, these are:

1. **Domestic heating (with sulphur-rich fuel)**: this source appears to have the strongest impact on the urban background concentrations in wintertime air pollution episodes when fine particulate concentrations and sulphur dioxide concentrations are peaking and correlate strongly with other burning-related pollutants such as CO, NO_X, SO_2, $PM_{2.5}$ and PM_1.

2. **Road traffic**. According to the emissions inventory, traffic emissions are one priority source of NO_X and $PM_{2.5}$ emissions. Traffic emissions also have a strong impact on air quality as they are released close to the ground.

3. **Uncontrolled burning of waste.** Emissions from domestic burning of garden material and mixed household waste are included in the emissions inventory, and do not make a large contribution to Bishkek's emission totals. Emission estimates have also been made for the landfill fire, but they are not included in the totals because the landfill is outside the city boundary. Nevertheless, the landfill fire is reported to have a significant impact on the air quality near to the landfill and is something that should be addressed as a priority.

These key emission sources have been identified based on the air quality data available for this study. When sources are better characterised (either through better monitoring or emission estimates), it will be possible to better determine the key next steps in managing air quality. However, even with limited data, it is possible to make some recommendations.

Priority policies to reduce the emission load of these three identified key emissions sources along with emission reduction scenarios are presented in **Chapter 9.**

1. **Domestic heating** - Affordable alternatives to households using sulphur-rich coal in the traditional solid-fuel stoves for heating the households in the Bishkek city area are quickly needed. Any kind of burning of solid fuels, particularly coal, by households should be avoided. In terms of air quality, it is better to produce the heat and electricity by using coal in the CHP station, which operates with a higher efficiency and emission control than by the households, so expansion of electric heating and the CHP network would be good options. Other options for alternative heating systems could be e.g. heat pumps or electric heating provided by substantially increasing the renewables generation capacity, such as hydroelectricity. Other options could be to install roof-top solar heating and hot water production. These types of systems are used in Rome or San Francisco which are in similar latitudes to Bishkek.

   It is also important to improve the energy efficiency of new and old houses and buildings to reduce the energy needed for heating. Regulation for energy efficiency of the buildings is needed. Also, the financial support instruments and models from the government for the households to improve the energy efficiency of old houses or for investing in new heating options and equipment such as heat-pumps should be considered and studied. Taxation can be an effective means of guiding society and the economy, as well as loan guarantee models to support climate and air quality friendly household investments. Financial support and affordability of alternative options would likely increase the willingness of households to invest for cleaner heating solutions.

Additional measures could include promoting use of electricity over coal during peak pollution events, and supporting reforms within the energy and electricity sector to support and enable this, piloting heat pumps and other alternative technologies etc.

2. **Traffic** - Achieving emissions reductions from traffic emissions can be done through a variety of measures - improving the emissions standards of road vehicles and building up an attractive and well-functioning public transportation system as an alternative to using private cars are two of the more prominent policy options.

   Improving the environmental performance of the car fleet can be achieved by ensuring that vehicles are equipped with emissions control technologies. This might be achieved by promoting the sales of newer vehicles, encouraging older vehicles to be scrapped, and/or undertaking annual inspections to ensure that emission control technologies are not being removed.

   Similarly, it is important to set emission standards and limits for public transportation, as a modern bus can emit less than a hundred older private cars. Minibuses (marshrutkas) are used extensively in Bishkek and need to be included in any vehicle modernisation initiatives or controls and checks.

   Emission regulations for heavy duty vehicles are also essential for reducing emissions from this sector, and in the context of Kyrgyzstan and Bishkek, it is vital to start a phase-out of heavy-duty Soviet-era vehicles from the city roads. As with other vehicle types, modern lorries are considerably cleaner than older lories (potentially by a factor of more than 100 times).

   A review of fuel standards to assess the scope for improvement would also be a constructive step.

3. **Waste burning, in landfill or by private households** - Building up a well operating waste management system including the collection, recycling, transportation and controlled landfill/waste incineration processes is necessary. It would be sensible to consider investing in a modern waste to energy plant, rather than using landfill. Modern plants operate to clearly defined emission standards such as the EU Industrial Emission Directive (IED) (EU, 2010). A waste to energy plant could then provide added electricity and heat capacity to the city.

   It would also be sensible to ensure improved waste management at the landfill to extinguish the current landfill fire.

   There is thought to be relatively little domestic waste burning or illegal dumping. However, collection of green waste for composting could be a useful investment to discourage domestic burning and create a useful supply of compost for Bishkek green spaces.

4. **Awareness-raising and education** - It is important to share information about the impact of different actions on air quality so that households, people, authorities, and decision makers can make better choices and decisions in everyday life to reduce emissions released into the air. It is also important to share information about the impact of air pollution, so that citizens can reduce their own exposure to high concentrations of pollutants in the air (for example, by wearing mask outdoors or keeping the windows closed during severe episodes).

5. **Long-term targets (i. e. until 2030 and 2040)** to replace the use of fossil fuels by renewable energies such as hydro, solar and wind energy. This supports climate action and improves air quality.

4.4 Roadmap for Implementation of the Priority Policies and Measures

Air quality can be improved by lowering emissions that reduce air quality, influencing the spread of air pollutants, and reducing people's exposure through various means. Thus, there should be a long-term national air pollution control programme that defines the nation level priority areas and key measures for emission reductions and improvement of the air quality in the long term (i. e next 10-15 years).

Targeted action plans are also needed at a more local, city level. For example, in the European Union, if the air quality limit values set by the EU are exceeded in a municipality (city), the municipality is obliged to draw up an air quality plan with measures that will allow the municipality to fall below the limit value as soon as possible. As an example, from Finland, the City of Helsinki has such a plan, because the annual limit value for nitrogen dioxide has been exceeded in some places on the busy streets of downtown Helsinki. In addition to reducing traffic emissions, Helsinki's Air Quality Plan for 2017–2024 includes measures to reduce emissions from street dust and wood burning. Helsinki reports on the implementation of the plan annually to the Ministry of the Environment and the regional environmental authority, Uusimaa ELY Centre. The plans from European Union Member states are also submitted to the European Commission for scrutiny and review. Member States can be fined if they do not meet their emissions reduction commitments.

According to the EU's air quality legislation, in the event of a sudden deterioration in air quality, cities must take measures to improve the air quality and protect residents (EU, 2008). The Helsinki metropolitan area has a joint Air Quality Action Plan for such situations (City of Helsinki, 2016). The plan includes a traffic management plan for air pollution episodes, but it has never had to be implemented in the Helsinki metropolitan area. However, traffic management plans have been used in practice in many French cities such as Paris and Lyon in cases where air quality has rapidly deteriorated.

Measures to promote air protection often also reduce emissions that cause climate change. As a result, measures to promote air protection are frequently included in cities' climate and environmental programmes and strategies. For example, the use of low-emission vehicles and fuels, as well as the promotion of sustainable modes of transport and low-emission energy production, provide both air quality and climate benefits. Reductions in the emissions from wood burning are sought especially by means of communication and by promoting the development of cleaner fireplaces (similar measures for Bishkek could focus on coal use). Street dust is combated, for example, by imposing strong dust emission controls on building sites in city centres.

Thus, a good starting point for the roadmap for cleaner air in Bishkek is the current plan of Comprehensive Measures to Improve the Environmental Situation in the City of Bishkek and Sokuluk, Alamudun districts of Chui region for 2021-2023. The current plan is halfway through its implementation time, thus preparation of a new plan after the current period is timely.

It is recommended that the new plan would be longer-term and cover a longer time (for example 2024-2030) as implementing the targeted measures for air pollution control takes time. In case there is a separate national air quality management plan defining priority area(s) on pollution reductions at national level, the Bishkek air quality management plan should be aligned with it and support the national level emission reduction targets. Examples of this integrated approach can be seen in the national air quality management plans compiled by European Union Member States (National Air Pollution Control Programmes) which are submitted to the European Commission for review.

A wide range of different stakeholders including the most vulnerable and affected people among others need to be involved in the design, development, and implementation of an air quality management system, as typically air quality improvements and emission reductions require considerable financial resources and budgeting, and importantly, commitment from all stakeholders. Thus, different Ministries need to agree on the objectives/targets and the roles that they play in achieving them.

Clearly it is important to understand how the effectiveness of policies and measures can be optimised and to ensure the best return on any expenditure. Consequently, cost-benefit studies will need to be undertaken before policies and measures are agreed.

It is important to define the priority areas for planning the long-term emission reductions. Measures should target these priority areas. Implementation of the measures requires a detailed action plan and follow-up plan. This action plan should also adopt a gender equality and right based approach as a way of solving this environmental concern. For instance, since women are more exposed to domestic heating which is the major source of air pollution in Bishkek, their participation and ideas should be considered in the design or implementation of any measures.

Three different emission reduction scenarios and their impact on emissions are presented in **Chapter 9** and identified key emission sources are presented in previous **Chapter 4.3.**

4.5 Coordination Between Different Stakeholders and Donors

The assessment team, particularly local experts, and UNEP and UNDP are well familiar with stakeholders in the air quality field in Bishkek. Relevant technical/national stakeholders are representatives of government agencies e.g. Ministry of Natural Resources, Ecology and Technical Supervision, Office of the Prime Minister, Ministry of Health, KyrgyzHydromet and its responsible ministry, Ministry of Emergency Situations, Bishkek City Hall and city administration; NGOs, civil society, community groups, and activists e.g. from environmental, civil rights, health, and other sectors; the private sector. Other important stakeholders as well are development partners, and diplomatic missions e.g. the US Embassy; and academics.

In air quality management, coordination between different stakeholders is important so that all stakeholders share the same vision and goal towards clean air in Bishkek. Through accessible expert presentations and workshops, stakeholders have been educated and informed about air pollution, its causes and consequences, and air quality issues. This is an important step in creating consensus on the evidence and facts around air quality issues.

Communication and coordination are important for exchanging the information, study results, and for coordinating the different activities so that they can supplement and support each other and to prevent the overlapping activities.

Stakeholder coordination is currently carried out through regular multi-stakeholder meetings organised by NGOs, and international groups and actors. Multi-stakeholder meetings are platforms for stakeholders to present varying perspectives, discuss issues, negotiate, and draft collective agreements. Small group meetings between stakeholders and the assessment team are used to review technical topics, inform of the stakeholder engagement process, address issues, and further engage and support stakeholder participation.

Results and outcomes of this assessment have been presented in stakeholder meetings, at the UNEP-UNDP-AUCA Air Pollution Seminar "Tackling air pollution for improved health and a greener future" (October 2021) and at the 1st conference of the Regional Central Asian Air Quality Dialogue Platform in Bishkek (March 2022), supported by the US Department of State and UNEP. Additionally, development partners have participated in several other donor meetings during the project.

4.6 Recommendations for Strengthening the Air Quality Management Systems

Considering the high pollution concentrations and the population (1 million) in Bishkek, the current air quality monitoring network is not sufficient for providing reliable air quality information to support decision-making and to inform and protect citizens. Currently, there is only one automated air quality monitoring station operated by KyrgyzHydromet, which is sited in an urban background location in Bishkek. More air quality stations are needed for different types of environments in Bishkek: traffic, industry, urban background, and regional background stations, because the level of pollution and impact of different emission sources varies depending on the area of the city. The acquisition of expertise in air quality dispersion modeling systems for the local experts and institutions is also recommended. Also, the model input data (emissions, activities, background concentrations, meteorological observations) for Bishkek in many air quality models could be improved.

There are an increasing number of air quality sensors and sensor networks in Bishkek city operated by different organizations. Sensors are indicative air quality monitoring tools which can be used to supplement the reference level monitoring stations, but the quality of the sensors does not meet the EU requirements of compliance monitoring (EU, 2015). Therefore, there is a need to enhance air quality monitoring networks and to carry out more detailed analysis such as source apportionment study to support decision making and preparation of clean air action plans. Modernization of air quality legislation is also important. Kyrgyzstan's existing air quality legislation is not in compliance with the latest international recommendations and does not take in account the latest knowledge about the negative impact of air pollutants.

4.6.1 Improving the Quality and Coverage of the Air Quality Monitoring Network

The planning and setting up of an air quality monitoring network (AQMN) is an important task for environmental protection authorities. Authorities need to plan and set up a well-targeted AQMN, both systematically and in a cost-effective manner. Defining the objectives for measurement will influence network design and optimize resources used for monitoring. It will also ensure that the network is specially designed to optimize information on the key issues at hand (**Figure 9**).

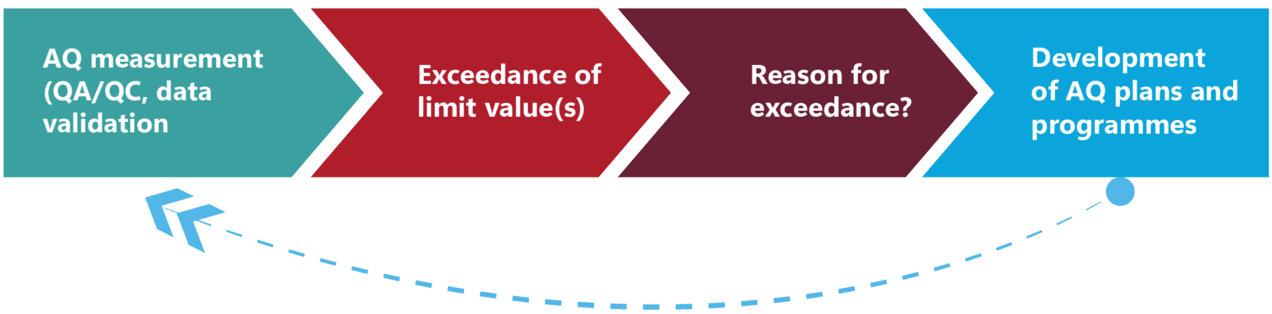


Figure 9 Well planned Air Quality Monitoring System is the cornerstone of efficient air quality management process.

The main objectives for the development of an air quality measurement and surveillance programme are related to:

- Population exposure and health impact assessment including collection and analysis of sex-disaggregated data where possible
- Identifying risks to natural ecosystems
- Identifying and attributing pollution to different sources
- Ensuring that industrial emission sources comply with their environmental permits
- Determining compliance with national or international Air Quality standards
- Informing the public about air quality and establishing alert systems
- Providing objective input to air quality management and to transport, land-use and industrial planning
- Developing policies and setting priorities for management action
- Developing and validating management tools such as models and geographical information systems
- Quantifying trends to identify future problems or progress in achieving management or control targets.

The following **Figure 10** illustrates the basic elements of the design of AQMN. Input information on activities and emissions in the study area as well as resulting atmospheric pollutants is necessary.

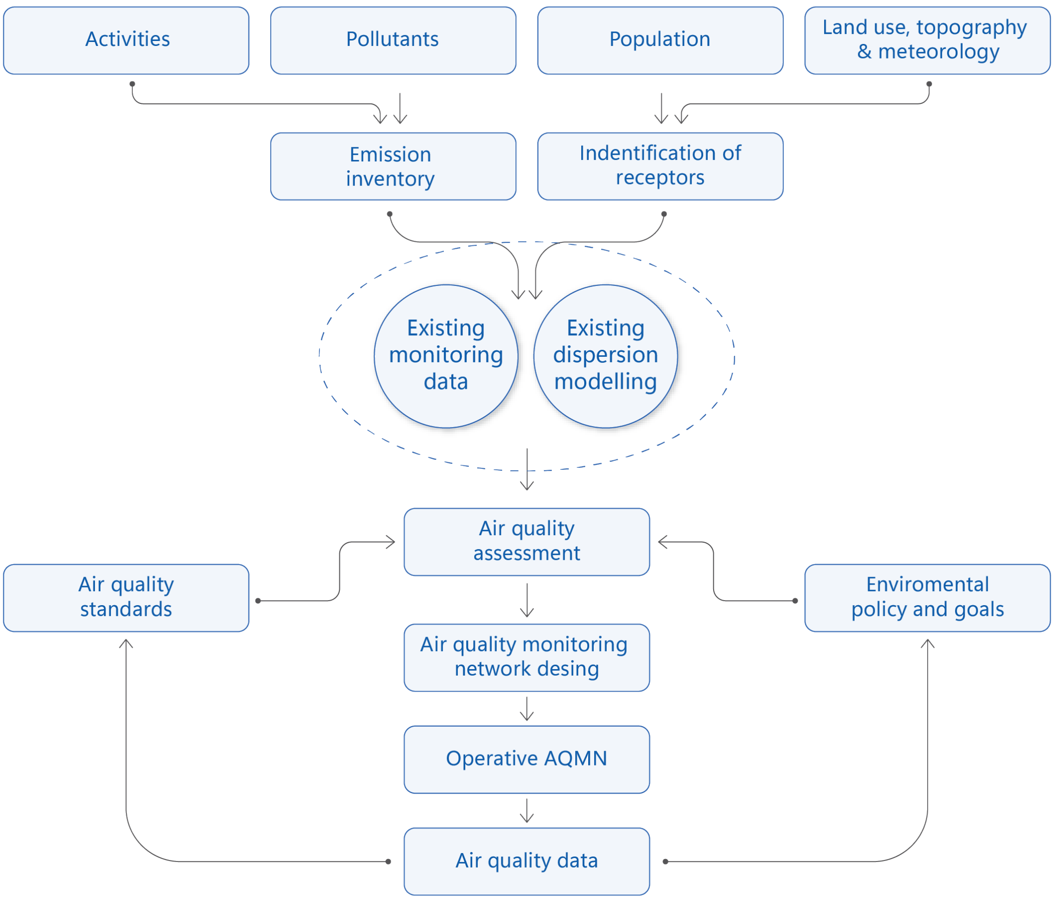


Figure 10 Example of basic elements of the design of the air quality management system.

Information on population (disaggregated by sex and socio-economic status), land use, topography and meteorology are also needed for the identification of objects for protection and to estimate the dispersion of pollutants. In the optimal case, there are some existing monitoring data and dispersion model results, on which authorities can base their air quality assessment and further the monitoring network design; otherwise, the design must be based on expert evaluation using initial informational inputs.

Other boundary conditions to the design of AQMN come from national environmental policy and goals and existing air quality standards. In countries with advanced air quality legislation (e.g. the US and member states of the EU), the legislation sets very detailed rules for AQ monitoring; where and when monitoring should begin and which compounds and methods should be used (e.g. EU, 2008; NAAQS, 2011). In developing countries, this legal framework may be inadequate or missing – and a gap analysis should be performed to harmonize existing systems with those of best international practice. International organizations have also developed useful AQ guidance focused on their own expert areas; for example, the WHO on health-related air pollution issues and the World Bank on best AQ practices for industrial facilities.

In each country the development of the AQMN(s) and the supporting legal framework should be viewed as converging processes which can benefit from the adoption of existing successful approaches.

4.6.2 Air Quality Management Process

Cooperation between different stakeholders (political decision makers, authorities, expert institutes and universities, industry/polluters, NGO's, media, citizens etc.) is crucial at national, sub-national and local levels for efficient air quality management. To mitigate for example transboundary pollution, regional and international cooperation is also needed. The whole air quality process is iterative and includes many levels of activities, including development of policy/legal framework, setting AQ standards, monitoring and assessment of air quality and its impacts, planning measures to improve air quality and mitigate problems, permitting, implementation and enforcement of actions and compliance monitoring (**Figure 11**). None of these activities alone are sufficient to achieve the objective of improved air quality and all steps are linked and/or pre-condition to each other. AQ monitoring and assessment, based on accurate information on the pollution level, is a vital element and at the core of the process.

The air quality management process also needs a clear leader, a nominated institution that is given the mandate (by law) to be responsible for coordinating, managing, and supervising the air quality management process. The process needs long-term goals and commitments for implementing the activities to receive the goals. Emission reduction actions and measures are necessary to improve the air quality. Most of the measures require considerable investments and an allocated budget from government or city administration, thus cost-effectiveness assessments of planned priority actions should be made. Priority actions should be gender-sensitive and targeted to the emission reductions with the highest possible impact on decreasing pollution. The impact of the implemented measures should be monitored.

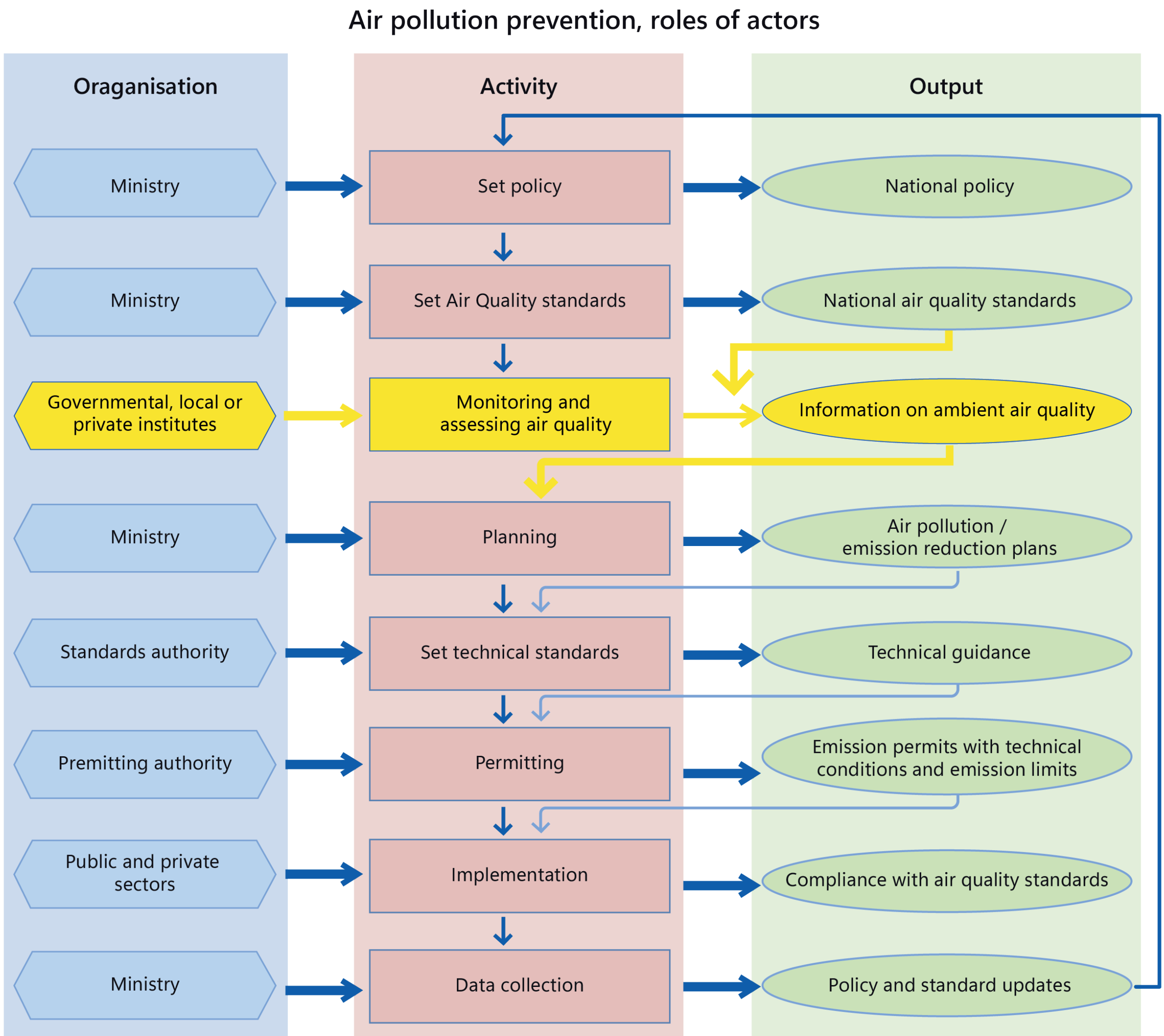


Figure 11 Simplified air quality management process with responsible organization.

4.6.3 Data Availability

It is very important that all air quality data is made available in a comprehensible way and with data which are standardized. The data needs to be accessible to the public, decision-makers, and research scientists so that anyone interested in air quality can find the information. Publishing the data also typically sets high criteria for the data quality. Thus, publishing the data also can enhance the quality assurance and quality control (QA/QC) of the data. For example, both online air quality data and historical data should be available and free for anybody to download it in electronic form. In order to develop the emissions inventory, it is important that all kinds of statistical data is also available. Without data availability it is very challenging to make in-depth air quality assessments and studies.

In the European Union, the INSPIRE directive (Directive 2007/2/EC) aimed to enhance the sharing of environmental spatial information among public sector organisations to better facilitate public access to environmental information across Europe. The directive created a European spatial data infrastructure that enables spatial information to be discovered, viewed, and downloaded in order to assist in policy making across boundaries.

4.6.4 A Preliminary Roadmap of Prioritised Development Activities

Improvements to existing tools, analysis and datasets have been proposed throughout this report. We present here an initial indication of how a realistic timeline of activities might look. The proposal below requires further discussion and development, and in particular consideration given to the level of local capacity. It is recommended to undertake the work in conjunction with international experts. An indicative workplan for implementation of the Roadmap for developing the different components that would comprise an air quality management system for Bishkek (and Kyrgyzstan more generally) is presented in **Table 8.**

A. Reviewing institutional arrangements

Assigning the roles/responsibilities for air quality management: Air quality management requires the involvement of many different governmental ministries, departments, organizations, and technical groups of experts. Responsibilities for the different technical work (operating the monitoring network, compiling the emissions inventory and projections, delivering policies in different Ministries etc.) need to be assigned to the most appropriate groups/organizations. The work also needs to be well coordinated, and the formation of an inter-ministerial group is usually desirable to achieve good coordination, co-operation, and effective flow of data across the different stakeholder groups.

A review could be undertaken within the next several months. However, implementing any recommendations is likely to take a long time, as it would involve changes to current roles, responsibilities, and would require adequate funding to be secured (see below).

Developing and funding local capacity: It is important to ensure that there is sufficient local expertise and capacity to initially benefit from working with international projects teams, and ultimately develop into a stand-alone local resource. Specific measures must also be taken to ensure local expertise and capacity building efforts include women.

Following a review of institutional arrangements, capacity building and training could be arranged to develop local teams and ensure that they have the skills and tools to operate an effective air quality management system.

B. Improving the ambient monitoring network

The ambient monitoring network needs to be developed. It is suggested that 3-5 new automatic multi-component monitoring stations for different city location types are installed as a first phase. Also, a data acquisition system for air quality data should be set up and an air quality portal disseminating the real-time air quality data should be established. Also, building up or enhancing the capacities (training) the staff of the local institution responsible for air quality monitoring around modern air quality monitoring and the related QA/QC processes is important (across ~18 months):

- 2 roadside monitoring stations
- 1 industrial monitoring station (if needed)
- 2 urban background monitoring stations representing different city areas (city centre and suburban).

A second phase is the addition of a regional background station in a rural location (about 50 kilometers outside of the Bishkek city area).

C. Improving the emissions inventory and projections tools

The current emissions inventory includes several assumptions and expert judgements, which means that it is not considered to be accurate enough to support policy development. More local data is needed to ensure that the emissions inventory represents the real-world circumstances in Bishkek.

Chapter 8.4.7 presents the priority improvement activities for the emissions inventory, and in particular the data that needs to be obtained. The priority sources sectors to improve are residential combustion, road transport and electricity and heat generation. Improvements could be made within several months if the relevant datasets exist, but it may be that new data needs to be collected for the first time, and it is then more realistic to plan some of the delivery across a one to two-year timeline.

It would be sensible for the local team who have already compiled national greenhouse gas and air pollutant emission estimates to be responsible for the Bishkek emissions inventory and projections.

D. Undertaking concentration source apportionment studies

Emission maps: Emission maps are needed as input into the dispersion modeling that gives the concentration source apportionment. After the emissions inventory has been updated, the estimates of current emissions can be mapped. This would require the collection of numerous spatial datasets.

Dispersion modeling capabilities: It is not essential that local experts develop this skillset. It would be sufficient for international experts to undertake the dispersion modeling studies that provide the link between emissions and concentrations, and then make this available to the local team who will be developing and accessing policies and measures.

E. Design and implementation of policy interventions

Impacts of policies and measures: The impacts on emissions of different policies and measures can be combined to give an emissions scenario. These can be combined with the concentration source apportionment information to quantify how ambient concentrations change due to the policies and measures. This work can be done now by international experts, but the team responsible for the emissions inventory could be trained to undertake the emission projections modeling, and the resulting impacts on ambient concentrations.

Economic assessment of policies and measures: It is necessary to assess whether policies and measures are cost effective. So, as well as the impact on ambient concentrations, the cost needs to be determined. The local team could be trained in undertaking cost-benefit analyses of the highest priority (& no regret) policies and measures e.g. installation of home insulation, modernisation of residential heating appliances, ensuring that new vehicles do not have their emissions control equipment removed.

The outputs from this study provide a short-list of recommended policies and measures.

4.7 Recommendations for Severe Air Quality Periods

4.7.1 Episodes with Severe or Poor Air Quality

Air quality can quickly deteriorate for different reasons for a short or longer time period. Typically, there are two main reasons for the poor air quality: high emissions together with unfavorable meteorological conditions with poor mixing conditions of the air. Pollution concentrations can be elevated by the local or long-range transported transboundary pollution. The reasons for poor air quality episodes can be such as accidental release or leakage from industry, explosions, forest fires or dust storms. These are all unexpected events that are difficult to forecast without special tools. Forest fires or dust storms can be forecasted by the special operational air quality modeling tools such as the SILAM model (FMI, 2020). In some cases, air quality can be expected to deteriorate in certain time of the year – for example due to the domestic heating in wintertime, road dust during the springtime or due to the agricultural burning of crops at certain times of the year. When poor air quality is expected at certain times of the year (typical seasonal phenomena that is repeated annually), it is easier to be prepared and to develop tools and indicators for air quality forecasts and alarms.

An air pollution alert should be given when daily (or hourly) concentrations of air pollution rise significantly above normal levels, and relevant Government standards. WHO guideline levels can be also used as thresholds for alerts. However, they are not applicable for this purpose in case they are continuously exceeded. Alerts about poor air quality are usually given when the air pollution levels are likely to remain high for a period of some days. During such sustained levels of pollution people, particularly vulnerable groups, are more likely to have an immediate health reaction to air pollution, including respiratory or cardiovascular issues.

Governments typically acknowledge severe or dangerous levels of air pollution by reference to a daily Air Quality Index (or AQI) and these figures often are used to forecast for the days ahead. The Air Quality Index is a national figure based on short-term air quality measurements and is not the same as WHO Air Quality Guidelines which are long-term exposure measurements (WHO, 2019).

4.7.2 Recommendations for the Severe Air Quality Situations

Where air pollution levels become severe or hazardous, the local authorities may introduce stricter measures to restrict or limit activities such as driving or industrial activities in or close to city areas. Designated authorities are responsible for issuing warnings or alerts about poor and severe air quality situations and provide guidance on how people can protect themselves during this time. It is important to understand and to have knowledge about the cause of the severe air quality situation, so that targeted measures can be implemented. Limiting exposure and stopping activities that may add to the problem become priority.

Below some behavioral advised actions listed that should be followed in case of severe air quality situation:

Stay indoors as much as possible. During high-pollution episodes all people, particularly those at risk, children, pregnant women, and elderly people, should stay indoors as much as possible and away from roads with heavy traffic. External doors and windows should remain closed to reduce the penetration of pollution from outside. Particle pollution can get indoors, thus an air cleaner /air purifier can be useful. Air purifiers can be expensive, and they need to have an appropriate filter to be effective. *Avoid using an air cleaner that works by generating ozone, which will increase the pollution in your home.* Be cautious when the weather is hot. If it is too hot to stay inside with the windows closed, or if you are in an at-risk group, go somewhere else with filtered air. When air quality improves, open the windows and air out your home.

Create a clean room for sleeping particularly for young children or elderly persons. The best option is a room with few windows and doors. Keep the windows closed. Run an air conditioner or air purifier if it does not draw air from outdoors and it has an appropriate filter.

Avoid prolonged or heavy exertion outside. Avoid activities that make you breathe faster or more deeply. In the case of severe air quality, it is a good day for indoor activities, such as reading or watching TV. Consider wearing a proper mask. However, scientific evidence is limited on the effectiveness of masks against air pollution. The fitting of the mask is very important. Masks should provide a tight seal around the wearer's mouth and nose. This may be particularly difficult to achieve especially for children.

Prevent additional sources of air pollution indoors. By avoiding using anything that burns, such as wood/coal burning stoves, candles, and incense. Do not smoke tobacco products indoors.

Pay particular attention to keeping the rooms inside homes clean. Wet mopping and dusting is preferable to sweeping or vacuuming as these can stir up additional dust and particles. Many cleaning compounds/solvents can also generate high levels of indoor air pollution, although this is an emerging field.

Limit and if possible avoid unnecessary travel by cars, scooters and other motorized vehicles. This will not only prevent additional personal exposure, but it will prevent adding to already high pollution levels for others (WHO, 2019; AIRNOW, 2022).

Table 8 Indicative workplan for implementation of the roadmap for developing the different components that would comprise an air quality management system for Bishkek (and Kyrgyzstan more generally). It assumes significant input from international funding bodies and prompt facilitation from the government of Kyrgyzstan.

	2023				2024				2025	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
A. Reviewing institutional arrangements	○									
Assigning the roles/responsibilities for air quality management		○	○	○	○	○	○	○		
Developing and funding local capacity		○	○	○	○	○				
B. Improving the ambient monitoring network			○	○	○	○				
C. Improving the emissions inventory and projections tools	○	○								
D. Undertaking concentration source apportionment studies										
Emission maps			○	○						
Dispersion modeling capabilities			○	○						
E. Design and implementation of policy interventions										
Impacts of policies and measures					○	○				
Economic assessment of policies and measures					○	○				
Implementation of short and long-term air quality strategy actions							○	○	○	○

PART II - SCIENTIFIC BACKGROUND

BACKGROUND INFORMATION RELATED TO AIR QUALITY IN BISHKEK AREA

5.1 Bishkek City, Kyrgyzstan

Bishkek is the capital of Kyrgyzstan (**Figure 12**) with a population of approximately one million. Bishkek is in the Chuy Valley, at an altitude about 700–900 meters, just north of the Ala–Too Mountain range. At 40 kilometers south from the city, the highest peaks rise over four kilometers. Bishkek has a Mediterranean-influenced hot summer humid continental climate, characterized by hot summers and cold winters, and during one third of the year there is a need to heat buildings.

Kyrgyzstan is rich in hydropower which accounts for 70 per cent of electricity production, and the country possesses vast coal reserves. Bishkek has one central heat and power station (CHP) and a deteriorating district heating system, numerous large and small heat only boilers and individual heating systems. Most of the district heating system and the heat only boilers were designed for gas, but many of them have been converted to burn coal or use electricity since the 1990s when natural gas imports collapsed following independence. In addition, a substantial share of urban households uses inefficient solid fuel-fired heating appliances.

Figure 12 Location of Bishkek city. Google Maps, Terrain layer map image, 2021.

5.2 Meteorology in Bishkek

Meteorological data was retrieved from Bishkek meteorological station (42° 51′ 0.00, 74° 31′ 59.99) for 2018 to 2020. **Figure 13** represents the monthly mean temperature in Bishkek based on the measurement data. There is a clear seasonal cycle in temperature with the warmest months occurring from June to August and the coldest months in December and January. The warmest mean monthly temperatures can rise to over 25 °C during summer months and the coldest temperatures can decrease below 0 °C during winter months.

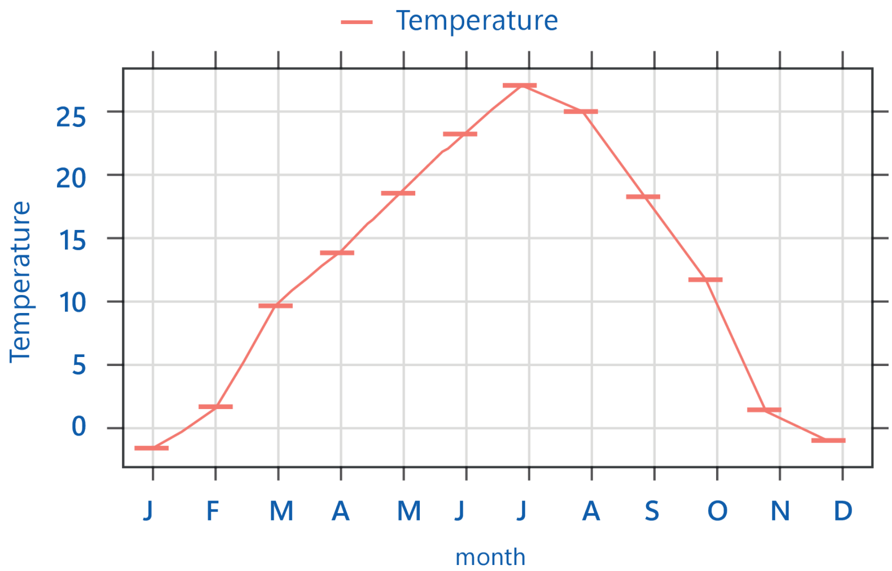


Figure 13 Monthly mean temperature in Bishkek based on data from 2018-2020.

Figure 14 represents the monthly rainfall at the Bishkek measurement station. Summer months are typically dry as the monthly rainfall remains well below 40 mm. The spring months, March, April and May are the wettest months in Bishkek. Annual rainfall varied from 406 mm (2020) to 609 mm (2018). Rainfall was exceptionally heavy during springtime in 2018.

Relative humidity in Bishkek is shown in **Figure 15**. June and August are very dry as the relative humidity drops to 35–40 per cent as the temperatures are high and there is less rainfall. From November to March the relative humidity remained above 60 per cent. Bishkek has a Mediterranean-influenced hot summer humid continental climate (Dsa) according to the Köppen climate classification.

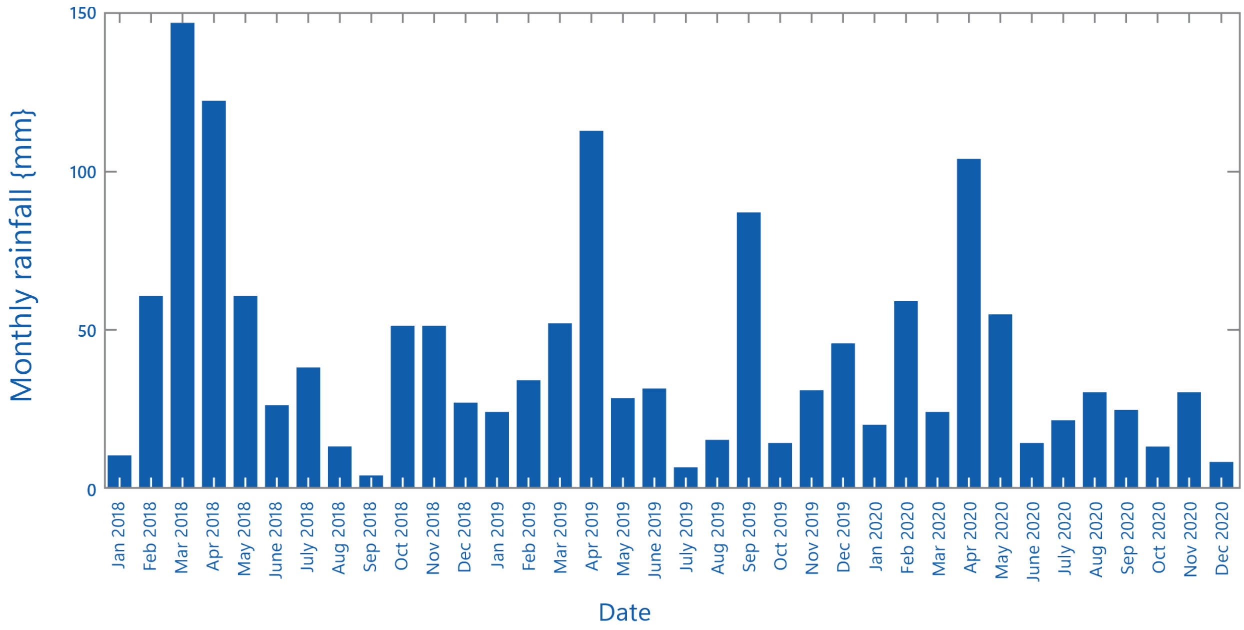


Figure 14 Monthly rainfall (mm) in Bishkek during 2018–2020.

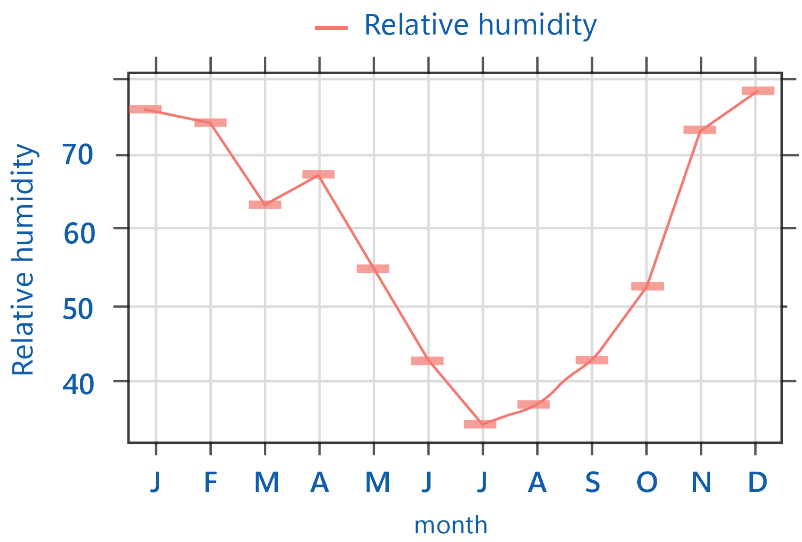


Figure 15 Monthly averaged relative (per cent) humidity (RH) in Bishkek.

Wind rose is plotted in **Figure 16**. According to this figure, Southerly and Westerly winds are the most common. During summer, autumn and winter months more than 15 per cent and during spring almost 20 per cent of the time wind blows from the West. The highest wind speeds (black and dark blue colour) were measured during Westerly winds. Low wind speeds (below 2 m/s, coloured with green) come most often from the South.

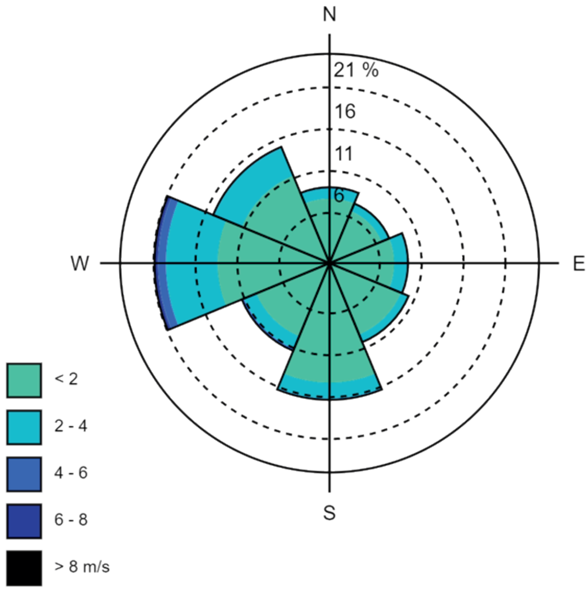


Figure 16 Windrose presents frequency of counts by wind direction (per cent) in Bishkek.

The dispersion of air pollutants occurs mainly in the lower part of the atmosphere, called the boundary layer. Boundary layer height defines the air volume where the emitted air pollutants can disperse and mix. The higher the boundary layer height is, the better are the mixing conditions for pollutants. The height of the boundary layer varies depending on the meteorological conditions and season. During nighttime and wintertime when there is no or little amount of solar radiation available, boundary layer height is typically less than 200 meters, but in summertime it can rise to over 500 meters. During surface temperature inversions (when the air at the ground level is cooler than the air above), which typically occur during nighttime and clear skies and nearby mountains, the mixing conditions are very weak and mixing layer height can be very low. The wind conditions of the boundary layer roughly determine the direction of airborne contaminants transport, but the turbulence of the airflows in the boundary layer and the height of it, significantly affect the mixing of pollutants and the dilution of pollutant concentrations. The key meteorological variables for dispersion of the pollutants are thus the direction and speed of the wind, the quantity describing the stability of the atmosphere and the mixing height.

Mixing conditions describe how well the air pollutants are dispersed in the atmosphere. Calculation of mixing conditions and mixing layer height is done with complex equations, which consider surface turbulent parameters and vertical profiles of the atmosphere from radio soundings. Mixing conditions in Bishkek are represented in **Figure 17**. As there were no radio soundings available, vertical profiles of temperature and wind were estimated from surface observations. The mixing conditions in Bishkek are typically weak, during summer season the mixing conditions are weak 50 per cent of the time and during winter season more than 85 per cent of the time. **Figure 18** shows that the mixing layer height in Bishkek is between 100 and 200 meters high 80 per cent of the time during January and December. Weak mixing of air and low mixing layer height cause air pollution levels to rise during wintertime as the volume in which the air can mix is smaller than during other seasons. The emissions from the ground are also typically higher during wintertime, which degrades air quality even more. The share of strong and moderate mixing conditions increases during spring months and the best conditions for mixing occur during summer months. In **Figure 18** the mixing heights class less than 100 meters is missing. This is due to the missing sounding data from the Bishkek area. The lowest mixing heights cannot be identified by the calculation method which is based on the Bishkek meteorological stations wind measurement data. For more detailed vertical profile of the atmosphere, also sounding data would be needed. Soundings are not carried out in Kyrgyzstan as they are not available on the WMO database.

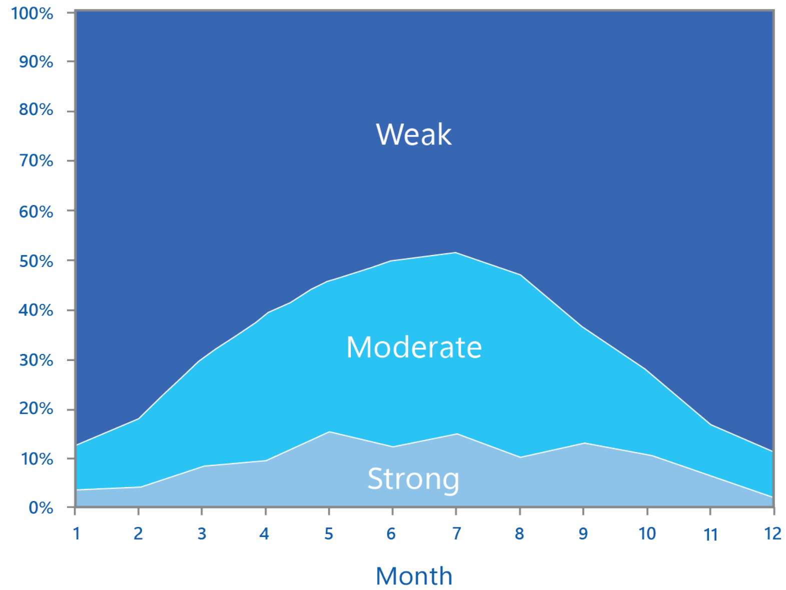


Figure 17 Monthly mixing conditions in Bishkek.

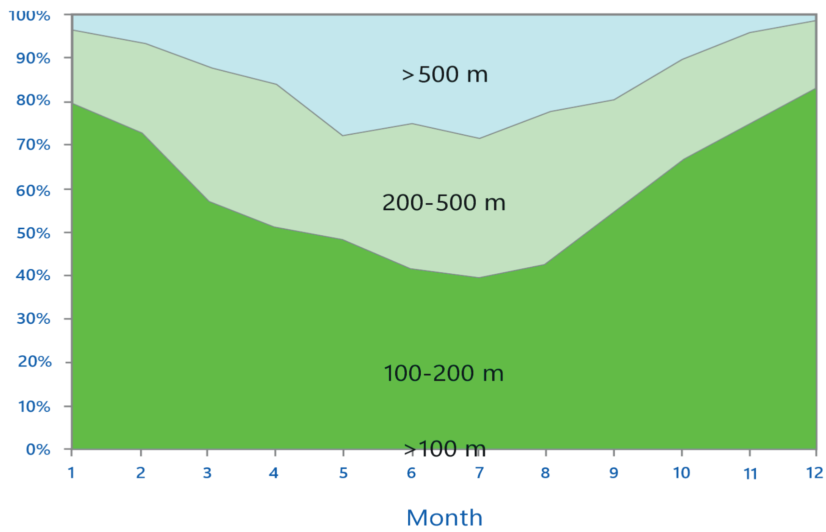
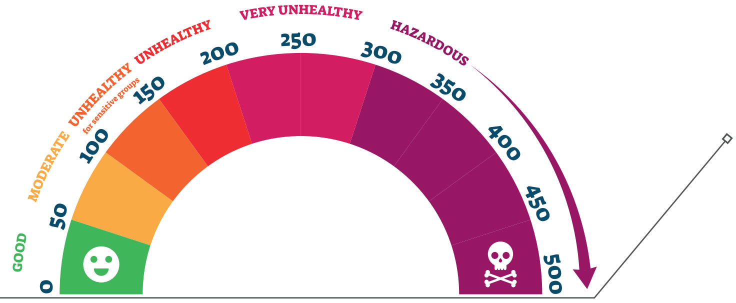


Figure 18 Distribution of boundary layer height in Bishkek.

In Bishkek the proximity of mountains influences the atmospheric mixing conditions in various ways. Mountains can cause thermal inversion in which cold air descends from the higher altitude areas and causes the boundary layer height to decrease. This can lead to high pollution concentrations at the surface as the air pollution is trapped in a smaller volume. Mountains can also block the wind and thus weaken the mixing conditions. In addition, there is orographic precipitation occurring in the mountains south of Bishkek. Much of the rainfall is received on the windward side (in this case south side) of the mountains and the leeward side tends to be dry in comparison. Orographic precipitation will both reduce RH (Relative Humidity) and increase temperature on the dry side of the mountain. Since there is less rainfall in Bishkek due to the mountains, the air quality is poorer than what it would be if there were no mountains as rainfall cleans the atmosphere from air pollutants through wet deposition.

6 ANALYSES OF THE AIR QUALITY MONITORING DATA IN BISHKEK



Currently, there are several different sources of air quality monitoring data available in the Bishkek area. However, there are only two; KyrgyzHydromet and the US Embassy air quality monitoring stations that provide hourly concentrations of priority air pollutants for several years' time, and the measurements at these stations are done by standardised reference methods or by equivalent method for standardised method. The US Embassy monitoring station measures only fine particulate ($PM_{2.5}$) and the KyrgyzHydromet station has almost all the priority pollutant measurements. Thus, this air quality assessment is mainly based on the data analysis of KyrgyzHydromet Air Quality Station as it is the most reliable and comprehensive data source based on the longtime of available monitoring data, pollutants measured, and the measurement techniques and equipment used in the station. In addition to these two stations, other air quality monitoring data sources available for this study were several low-cost sensor network data. The low-cost sensors used measure mainly fine particulates ($PM_{2.5}$), some of them also nitrogen dioxides (NO_2). There were some limitations on accessing and downloading of the hourly monitoring data provided by the low-cost sensors, as some of the data is available only as daily average concentrations instead of hourly values, or there was only data as air quality indexes available. Some of the sensors also had very low data coverage. Thus, evaluating the sensor data and its reliability was not easy. Therefore low-cost sensor data was considered as an indicative data source in this assessment.

The Department of Meteorology, Ecology and Environmental Protection of the Natural-Technical Faculty of the Kyrgyz-Russian Slavic University also has an automatic air quality monitoring station which has been in operation since 2017. However, the monitoring data of that station is not freely available for the public, thus it was not used in this study.

6.1 KyrgyzHydromet Air Quality Station

Kyrgyzhydromet automatic air quality station is located about 5 kilometers to the west from the city center (42.860728, 74.525031, **Figure 19**). The environment can be described as an urban background, residential area. The key material of this study is the airborne hourly concentration data set of CO, NO_X, SO_2, total suspended particles (TSP), PM_{10}, $PM_{2.5}$ and PM_1. The KyrgyzHydromet air quality station became operational in autumn 2015. Finnish Meteorological Institute supported KyrgyzHydromet with the establishment of the air quality station.

The KyrgyzHydromet air quality monitoring station is equipped with reference-level analyzers and equipment (**Table 9**). This site is maintained by KyrgyzHydromet with the support of Finnish Meteorological Institute.

Table 9. Air quality monitoring instruments at the KyrgyzHydromet site.

Component	Method	Instrument
CO	Infrared absorption	Model 48i Thermo Scientific
$NO/NO_2/NO_x$	Chemiluminescent	Model 42i Thermo Scientific
SO_2	Pulsed fluorescence	Model 43i Thermo Scientific
TSP	Laser nephelometer	Osiris, Turnkey
PM_{10}	Laser nephelometer	Osiris, Turnkey
$PM_{2.5}$	Laser nephelometer	Osiris, Turnkey
PM_1	Laser nephelometer	Osiris, Turnkey
Automatic Weather Transmitter		WXT520, Vaisala

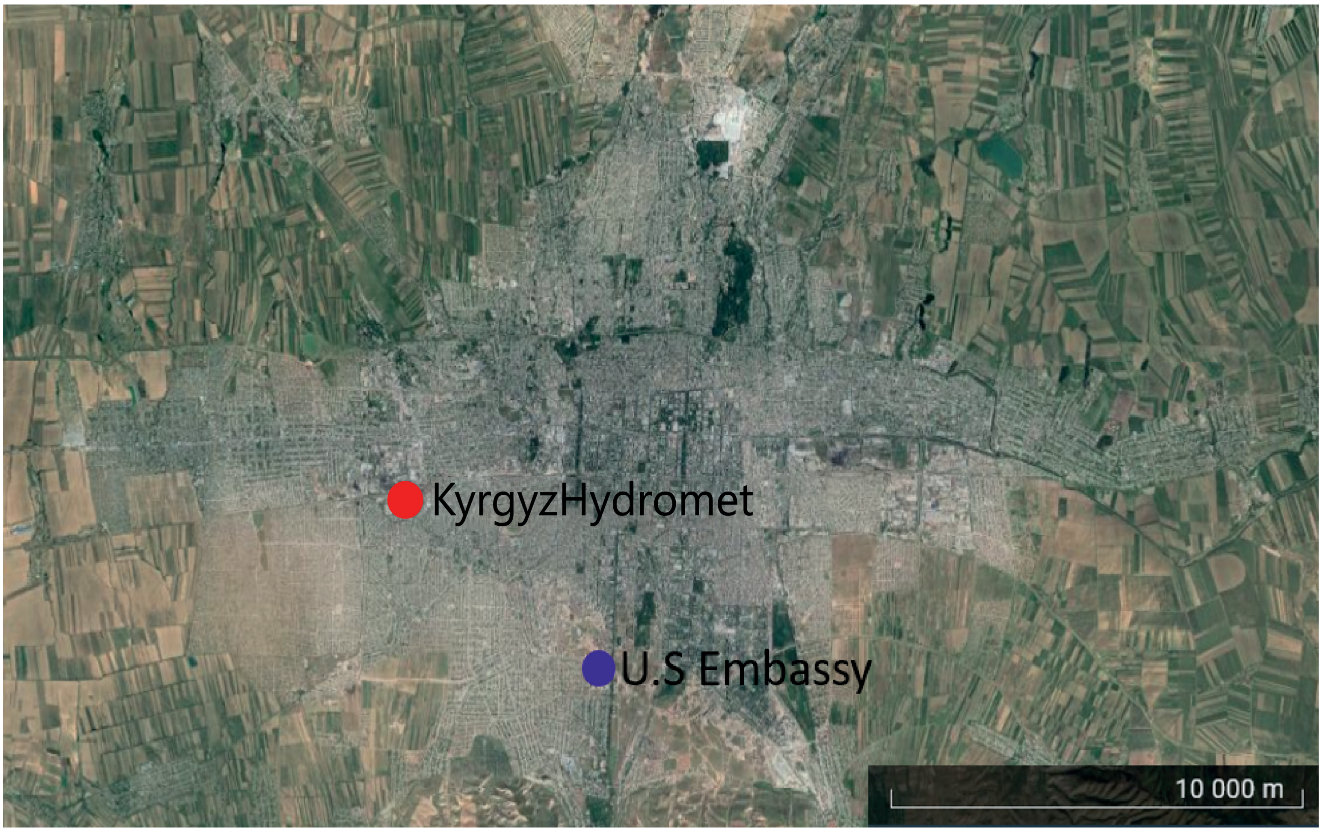


Figure 19 Location of the KyrgyzHydromet automatic reference site (red) in Bishkek City. Also, the US Embassy is marked (blue).

Carbon monoxide (CO)

Comparisons of the carbon monoxide concentrations measured at the KyrgyzHydromet station are presented in **Figure 20**. Wintertime peak concentrations of CO exceed the considered air quality standards (except the US hourly standard). In winter 2017/2018 during the four-month period November-February, the national daily standard was exceeded on half of the days (59/120 days).

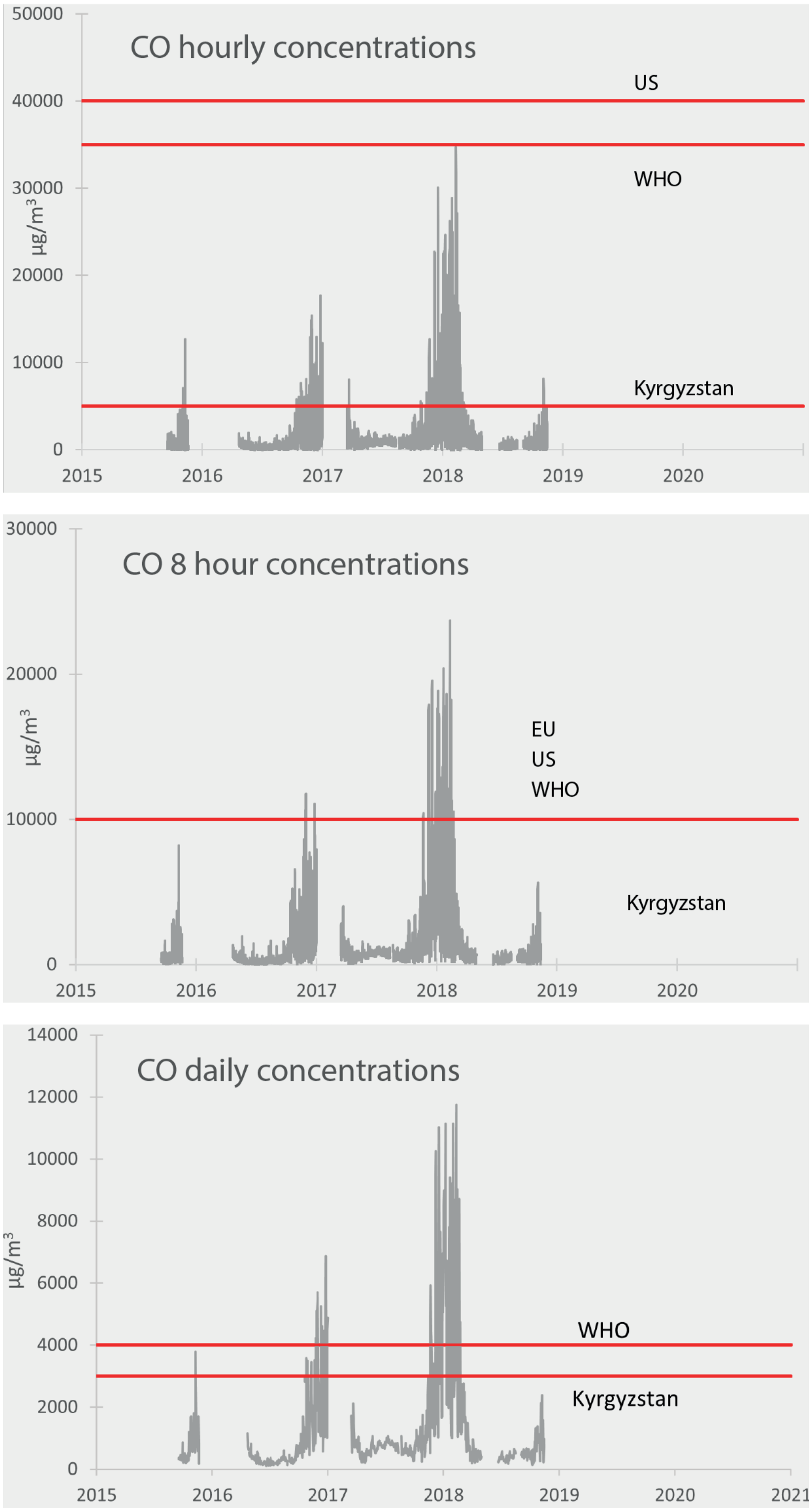


Figure 20 Comparison of the CO monitoring results of KyrgyzHydromet automatic reference station with the key air quality standards.

Nitrogen dioxide (NO_2)

International hourly air quality standards of NO_2 are exceeded during the winter peak season (**Figure 21**). Again, the Kyrgyzstan national standards, both hourly and daily, are exceeded severely. Meanwhile the annual means linger just below the European and WHO standards. It should be noted that KyrgyzHydromet monitoring station is not a busy traffic site, and as such these exceedances are worrying.

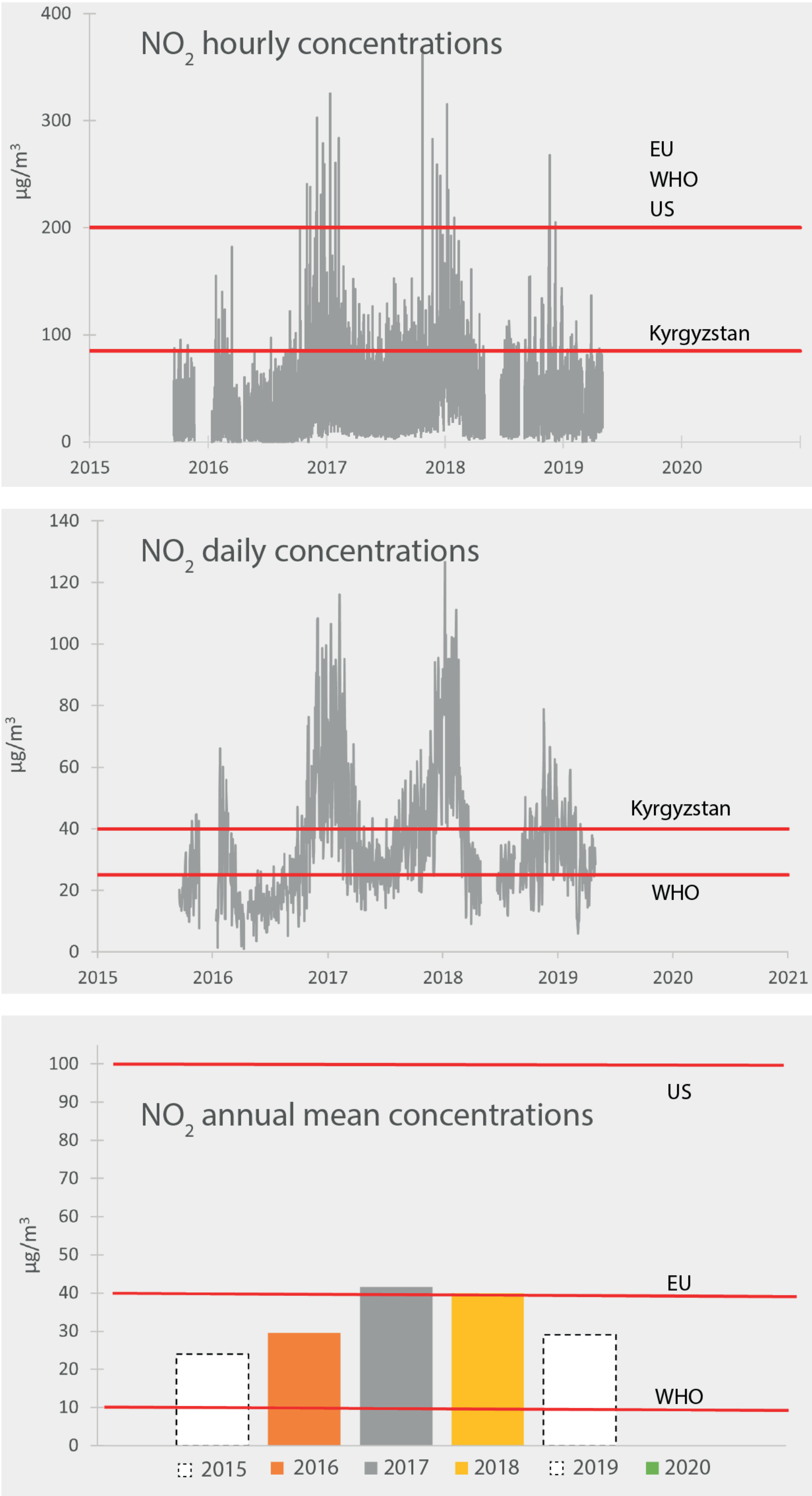


Figure 21 Comparison of the NO_2 monitoring results of KyrgyzHydromet automatic reference station with the key air quality standards. White bars mean that data coverage is less than 75 per cent that year.

Sulphur dioxide (SO_2)

For sulphur dioxide all key standards are being exceeded during the winter season, the most stringent ones seriously **(Figure 22).**

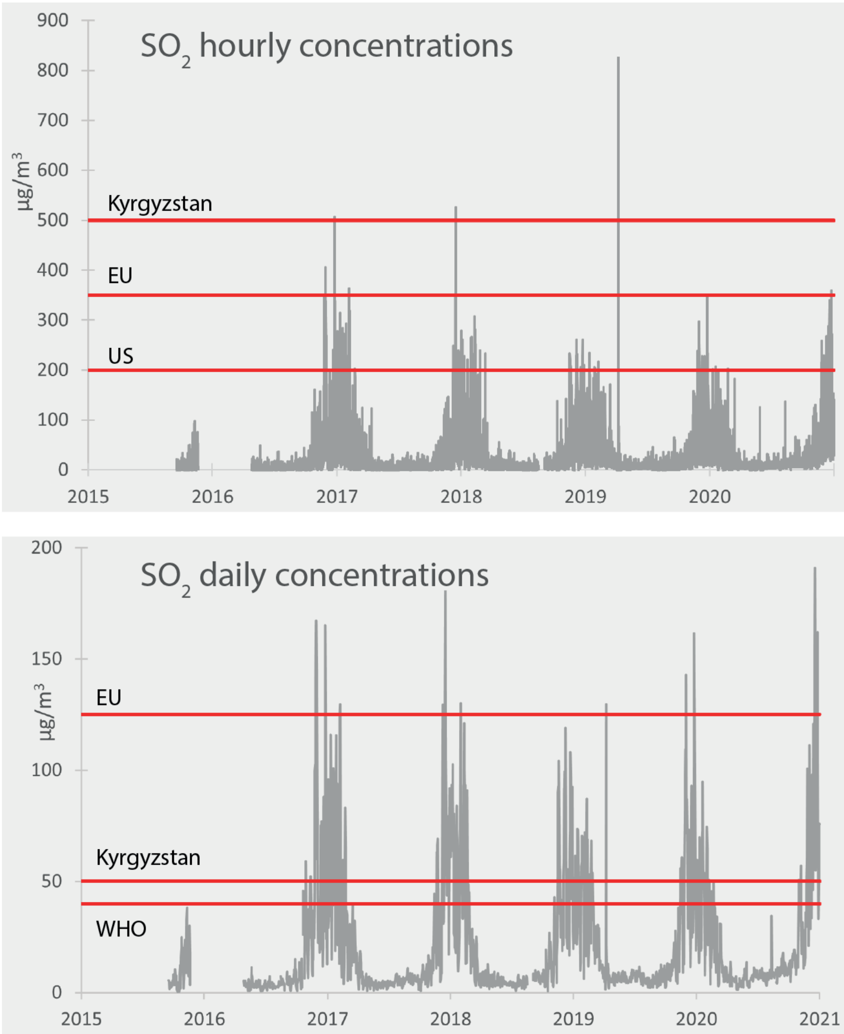


Figure 22. Comparison of the SO_2 monitoring results of KyrgyzHydromet automatic reference station with the key air quality standards.

Particulate matter smaller than 10 µm (PM_{10})

All key air quality standards for PM_{10} are being exceeded severely. Exceedances occur throughout the year (**Figure 23**).

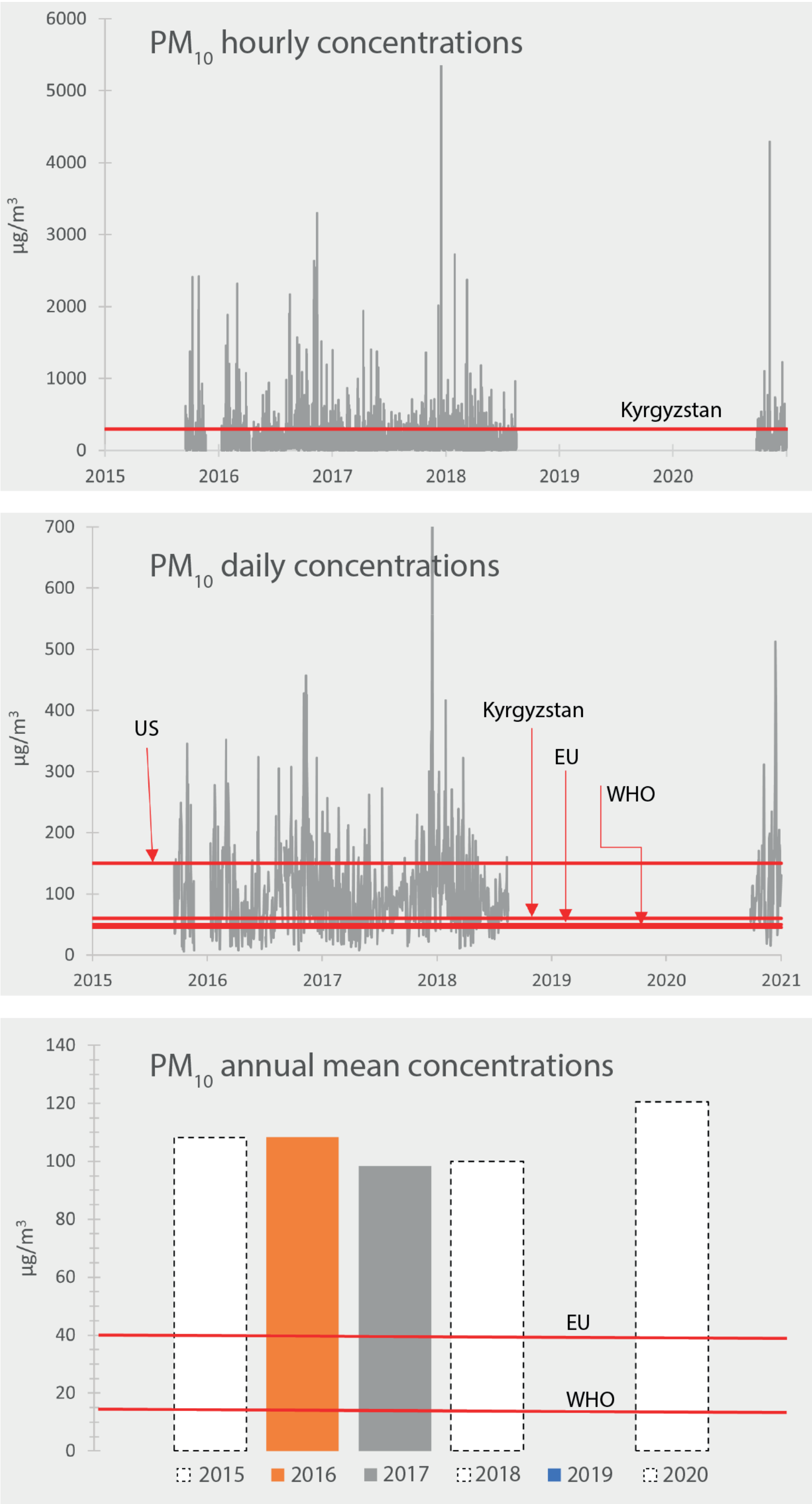


Figure 23 Comparison of the PM_{10} monitoring results of KyrgyzHydromet automatic reference station with key air quality standards. White bars mean that data coverage is less than 75 per cent that year. There was no data available from 8/2018 to 9/2020 due to technical problems.

Particulate matter smaller than 2.5 µm ($PM_{2.5}$)

All key air quality standards for $PM_{2.5}$ are being exceeded severely, while short-term standards are exceeded mostly during severe episodes which occur during wintertime. Even though the summer concentrations are reasonably low, the long-term level (annual mean) rises to an alarmingly high level (**Figure 24**).

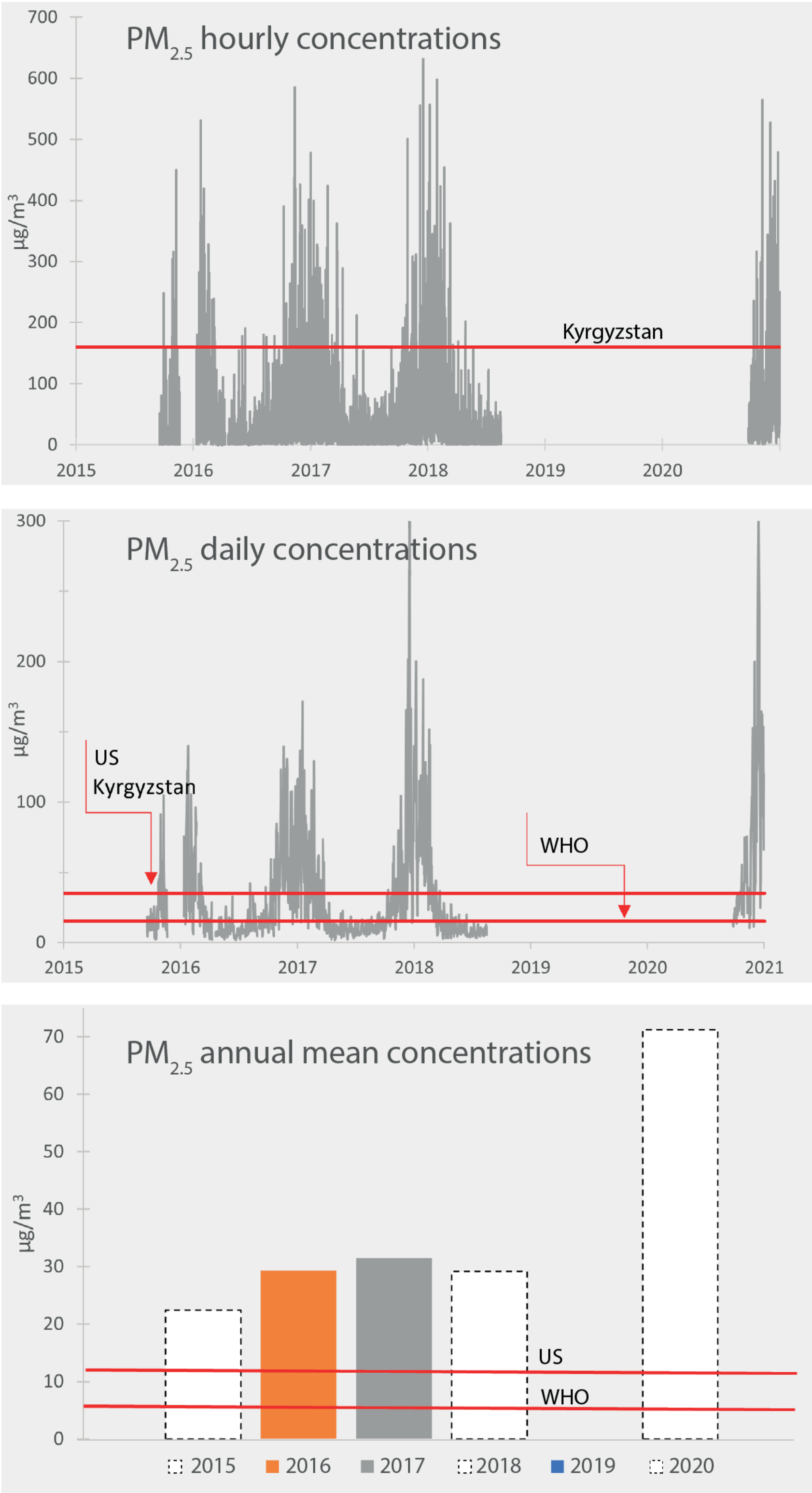


Figure 24 Comparison of the $PM_{2.5}$ monitoring results of KyrgyzHydromet automatic reference station with the key air quality standards. White bars mean that data coverage is less than 75 per cent that year. There was no data available from 8/2018 to 9/2020 due to technical problems.

Figure 25 shows the validated data in years 2015–2020. **Figure 26** shows the diurnal variation of all components, calculated annually. Significant deviations in annual behavior may indicate problems with measurement quality, but in this case, there are no signs of severe problems. For example, the anomalously high concentration values of $PM_{2.5}$ and PM_1 in 2020 are due to the fact that the measurement covered only a couple of months at the end of the year 2020.

All pollutants have the pattern of two daily peaks, one before noon and another late in the evening. This pattern is due to the combination of atmospheric mixing conditions and emission strengths. At midday, the mixing height (see also the wind speed) is at its peak and pollutants disperse effectively (afternoon minimum). After midnight, the emissions are at their lowest (concentrations start to decrease).

Fine particles (< 2.5 µm) have only weak morning peaks, the reason for this is not obvious, but could be an indication of reasonably small morning emissions. A similar observation can be made for TSP, PM_{10}, and PM_1. The difference between the morning peak and the evening peak seems to be more pronounced for particulate matter concentrations than for gaseous pollutants.

Of the meteorological variables it is interesting to note that the strongest winds at midday arrive from the west (along the Chui valley) and towards evening turn southwards and weaken. Remembering the topography of the Bishkek surroundings, this could be an indication of a mountain-valley breeze.

This phenomenon also has an impact on the air quality. The pollutants emitted in Bishkek during daytime tend to rise up to the mountain sides, and in the evening with the weak southern winds blow back to the city and enhance the strong evening peaks of pollution.

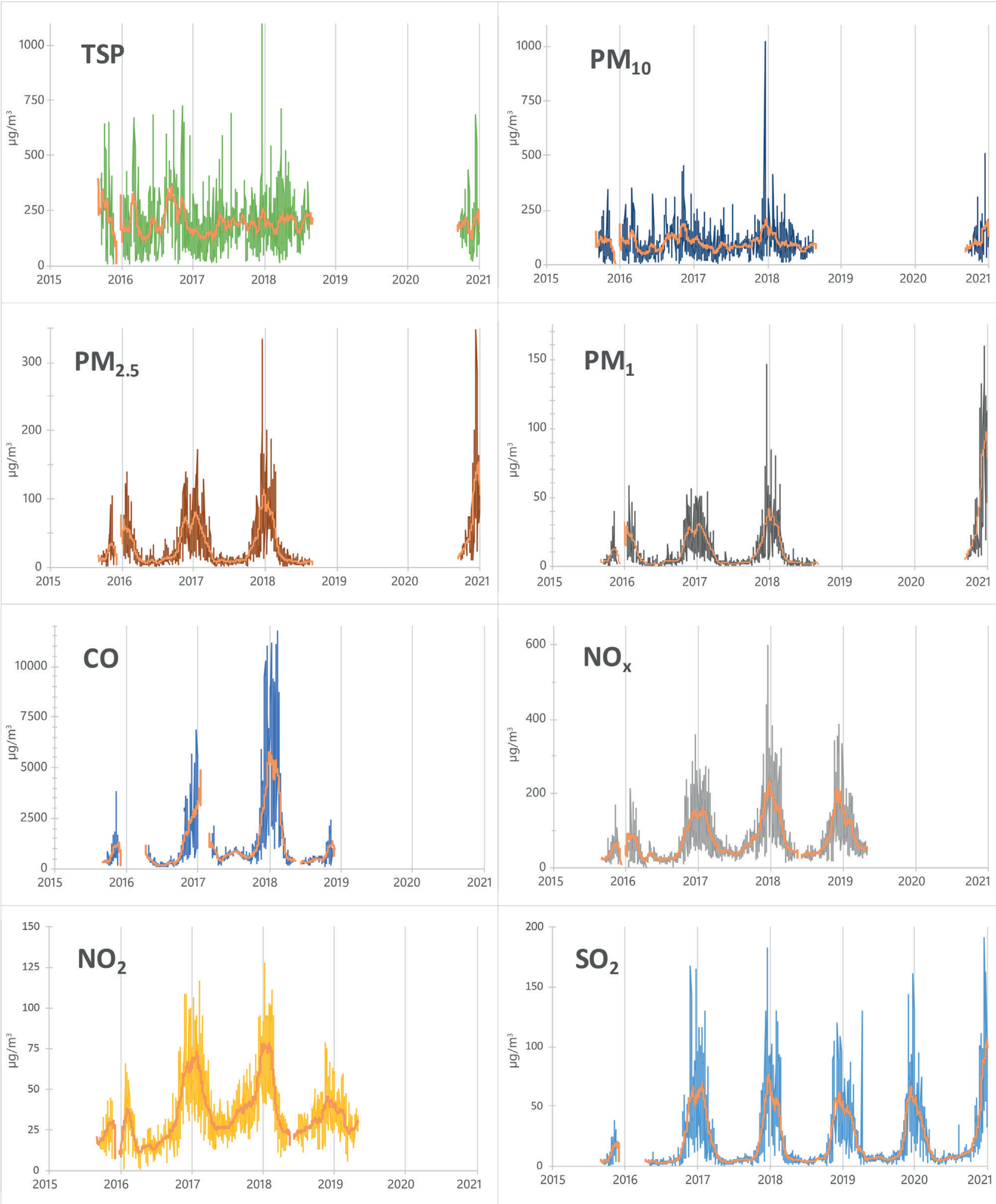


Figure 25 Validated data 2015–2020 from KyrgyzHydromet automatic reference station, daily means and 30 days moving average.

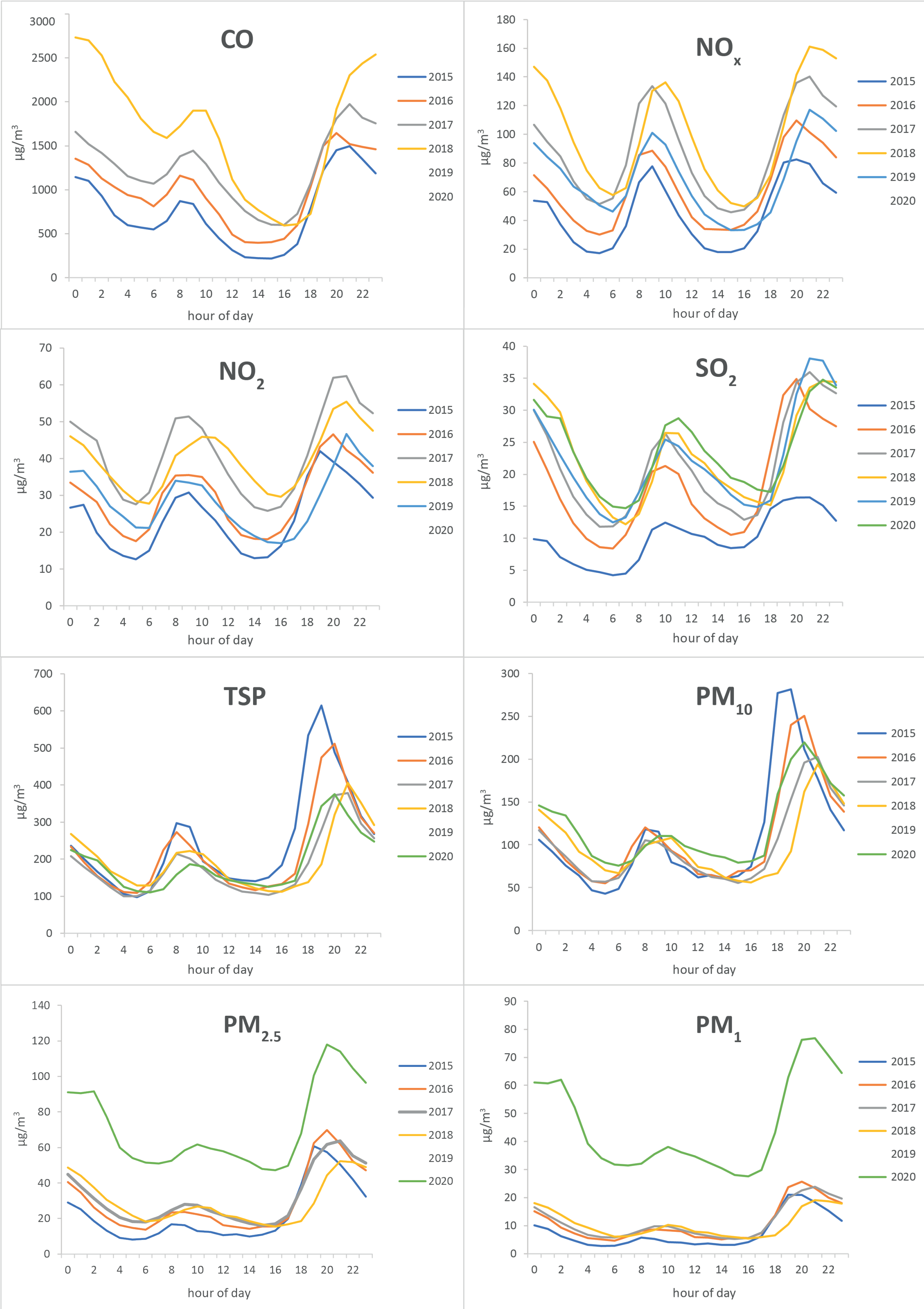


Figure 26 Diurnal variations of all variables calculated annually. There was no data available for PM from 8/2018 to 9/2020 due to technical problems.

Correlations Between the Pollutant Concentrations and Meteorological Variables

The correlation coefficient r measures the strength and direction of a linear relationship between two variables. The cross-correlation matrix shows the correlation coefficients for all variables of the data. **Figure 27** shows the cross-correlation matrix of the pollutant and meteorological data. The dark red color indicates a strong positive correlation and dark blue color indicates a strong negative correlation.

A strong positive correlation between CO, NO_X, SO_2, $PM_{2.5}$ and PM_1 was detected. These compounds most likely are emitted from combustion sources. PM_{10} is weakly correlated and TSP not at all with these "combustion pollutants". TSP is obviously dust and so is the coarse fraction of PM_{10}, which explains the weakened correlation with the combustion pollutants. The fine fraction ($PM_{2.5}$ and PM_1) of PM_{10}, though, results in a reasonable correlation with the other combustion pollutants.

	CO	NO	NO_x	NO_2	SO_2	TSP	PM_{10}	$PM_{2.5}$	PM_1	WS	WD	T	RH
CO	1.00	0.86	0.90	0.84	0.84	0.10	0.41	0.80	0.86	-0.40	-0.19	-0.58	0.21
NO		1.00	0.98	0.71	0.80	0.22	0.53	0.83	0.87	-0.49	-0.45	-0.52	0.17
NO_x			1.00	0.84	0.86	0.21	0.53	0.85	0.89	-0.51	-0.26	-0.56	0.14
NO_2				1.00	0.81	0.16	0.44	0.77	0.79	-0.46	-0.26	-0.52	0.04
SO_2					1.00	0.12	0.43	0.78	0.78	-0.44	-0.17	-0.62	0.20
TSP						1.00	0.88	0.34	0.24	-0.18	0.00	0.22	-0.41
PM_{10}							1.00	0.70	0.58	-0.35	-0.02	-0.15	-0.11
$PM_{2.5}$								1.00	0.94	-0.52	-0.01	-0.63	0.30
PM_1									1.00	-0.50	-0.03	-0.61	0.27
WS										1.00	-0.11	0.45	-0.22
WD											1.00	-0.03	0.11
T												1.00	-0.73
RH													1.00

r: ≤ 1.0, ≤ 0.8, ≤ 0.6, ≤ 0.4, ≤ 0.2, ≤ -0.2, ≤ -0.4, ≤ -0.6, ≤ -0.8

Figure 27 Correlation matrix of the daily concentration values and meteorological variables. WS= wind speed, WD= wind direction, T= temperature and RH= relative humidity.

CO, NO_X, SO_2, $PM_{2.5}$ and PM_1 are negatively correlated with wind speed, i.e. concentrations increase when wind speed decreases, which suggests that the pollution experienced in Bishkek is caused by local emissions, and thermal inversions during nighttime and wintertime as well as thermal inversions caused by the proximity of mountains (See **Chapter 5.2**).

SO_2, $PM_{2.5}$ and PM_1 are strongly negatively correlated with temperature (concentrations increase when temperature decreases), which strongly suggests these result from emissions from small-scale heating emissions with solid fuels. Wood combustion emissions are rich in fine PM ($PM_{2.5}$ and PM_1) but carry no SO_2. Thus, as SO_2 concentrations are also strongly correlating with other combustion pollutants measured in KyrgyzHydromet station, it is likely that sulphur-rich coal combustion has a role in the severe wintertime pollution episodes in Bishkek.

CO and NO_X have a weaker association with temperature, most likely because traffic emissions that are not season or temperature dependent, are also important sources of these pollutants, in addition to the wintertime heating related emissions.

TSP and PM_{10} do not correlate with temperature; dust is a year-round problem in Bishkek. On the other hand, TSP weakly correlates negatively with relative humidity (TSP increases when humidity decreases); on foggy, rainy days there is less dust.

Pollution Rose Plots

Pollution rose plots (average pollutant concentrations by wind direction sectors) can give information about the pollutants' source locations relative to the monitoring site. Red circles in the plots represent the average concentration during calm (very low wind speeds) situations. High concentrations during calm situations indicate the strong impact of emission sources near the monitoring station. **Figure 28** shows the pollutant roses of NO_2, NO, CO and SO_2 detected at the KyrgyzHydromet automatic reference station and **Figure 29** shows the pollution rose plots of particulate TSP, PM_{10}, $PM_{2.5}$ and PM_1. Pollution roses describe the average concentration.

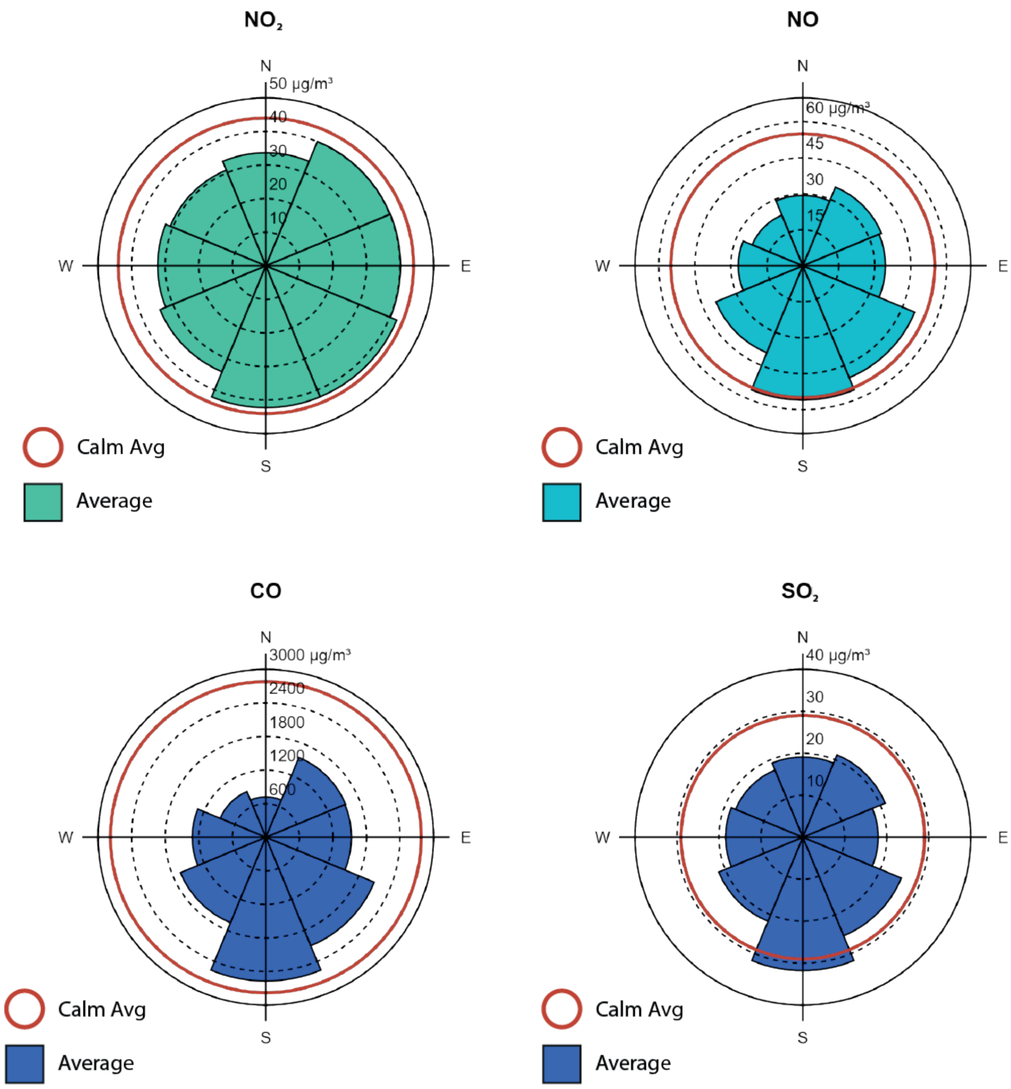


Figure 28 Pollution rose plots for NO_2, NO, CO and SO_2 at KyrgyzHydromet automatic reference station.

For all pollutants, the highest concentrations occur during calm (wind speed less than 0.5 m/s) conditions (with the one exception being the SO_2 south sector). This suggests that pollutants are of local origin, and most likely the wintertime emissions and episodes are enhanced potentially by long-lasting temperature inversions. The second highest concentrations occur during southern and southeastern wind directions. In these directions, a densely built area of detached houses spreads within a radius of several kilometers. For NO_2, the highest concentrations originate from the north-eastern and eastern directions more than for other pollutants, perhaps due to the transport of this secondary pollutant from the city center, located to the east of the KyrgyzHydromet monitoring station.

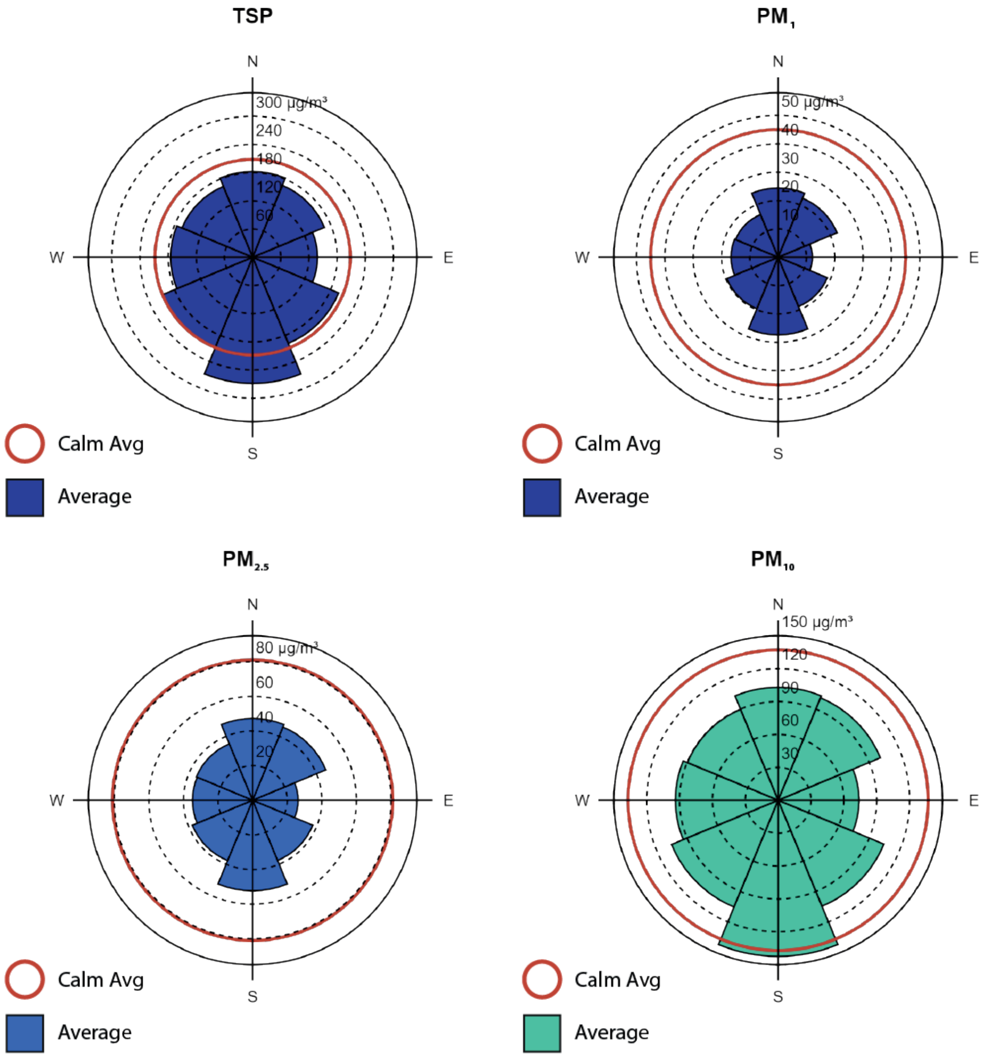


Figure 29 Pollution rose plots for TSP, PM_{10}, $PM_{2.5}$ and PM_1 at KyrgyzHydromet automatic reference station.

The highest concentrations of the larger particles, TSP and PM_{10}, are quite evenly distributed between the wind direction sectors, however with the southern sector slightly emphasized. Notably, the similarity of the smaller particles' ($PM_{2.5}$ and PM_1) "roses" with that of the gaseous SO_2 is striking. This is in line with the high positive correlation detected between these pollutants, suggesting a common, direct/primary source. Again, calm conditions trigger the highest concentrations. Obviously, the monitoring site is not impacted by any single dominating point source of SO_2 and fine particles ($PM_{2.5}$ and PM_1), but it seems that there are many scattered emission sources in different directions from the air quality station.

Proportions of Different Particle Size Classes

The PM monitoring results, divided into four size classes, TSP, PM_{10}, $PM_{2.5}$ and PM_1, provide further evidence on the sources of fine particulates ($PM_{2.5}$ and PM_1). Heating (combustion) related particulate matter emissions are formed only by fine particles (particulate size smaller than 2.5 µm) (**Figure 30**).

During summertime (when the total mass concentrations are lowest) the larger size fractions (>2.5 µm) contribute around 95 per cent of the total particulate matter mass, of which around 60 per cent is over 10 µm and 35 per cent between 2.5 and 10 µm, i.e. coarse particles.

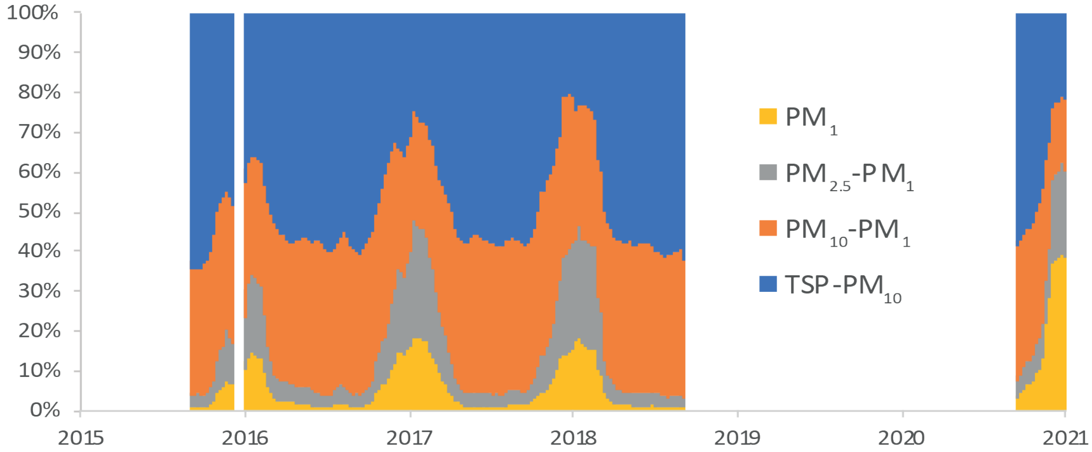


Figure 30 Percentage ratio variation of the particulate matter size fractions during the study period (visualized from 30 day moving average) at KyrgyzHydromet automatic reference station. There was no data available from 8/2018 to 9/2020 due to technical problems.

During the winter months, the portions of smaller fractions ($PM_{2.5}$ and PM_1) of particulate matter increase considerably. During the winter peak (December–January), fine particles (<2.5 µm) contribute up to 50 per cent of the total mass, the PM_1 fraction being almost 20 per cent. During this period, the share of the largest particulate matter size category falls to 20–40 per cent of the total fraction.

This indicates that fine particles have a serious wintertime direct emission source most likely related to the heating activities. Due to the strong correlation of fine particles and SO_2, the main emission source is most likely locally used sulphur-rich coal that is used for heating in wintertime. As the sources seem to be distributed in many different directions, it indicates that the reason is domestic heating.

6.2 The US Embassy Monitor, AirNow Platform

AirNow (AIRNOW, 2022) is the centralised data system of the US Environmental Protection Agency and other US governmental institutes providing air quality data and information. Among these are the current and historical AQ monitoring data for US embassies and consulates around the world. US embassies and consulates host reference grade air quality monitors and their results are displayed in a separate platform. The stations are set up to inform US personnel and citizens overseas. The location of the monitoring station of the US Embassy in Bishkek is shown in **Figure 19**.

AirNow measurements are collected by state, local or tribal monitoring agencies using federal reference or equivalent monitoring methods approved by EPA. Although preliminary data quality assessments are performed, the data in AirNow are not subjected to the full validation used to officially submit and certify data in EPA's regulatory database.

The AirNow data system does not include the detailed information of the type of the analysers used for air quality monitoring. However, the AirNow webpage states that measurements are done by federal reference or equivalent monitoring methods approved by EPA which indicates that the quality of the monitoring instruments used should be high as it is defined to be equivalent to reference methods. Therefore, US Embassy PM measurement data can be used as a reference data set when assessing the reliability of the air quality sensors used in the Bishkek area in a similar way as KyrgyzHydromet automatic station data can be used as a "reference station". However, it is important that when assessing the reliability of the sensors and comparing the sensor data against the US Embassy or KyrgyzHydromet air quality monitoring data, the sensors should be located nearby the station that they are being compared with. Otherwise, there can be uncertainty in the comparison due to the impact of local emission sources nearby the measurement sites. In case other reference stations are not available in the area, the US Embassy air quality monitoring station is a good option to be used as a reference station for assessing the reliability of the sensors.

AirNow maps and AQI readings use only ozone, PM_{10}, and $PM_{2.5}$ at this time. Most data is available within 30 minutes and is quality assured and released by the end of the hour. All raw data is freely downloadable.

6.3 Comparison of KyrgyzHydromet AQ and US Embassy $PM_{2.5}$ Data

In the last couple of years, new air quality monitoring has been set up in the city by citizens and other actors. KyrgyzHydromet air quality station became operational in autumn 2015. The US Embassy started the $PM_{2.5}$ monitoring in its premises in early 2019. **Figure 31** combines the KyrgyzHydromet and US Embassy monitoring results of $PM_{2.5}$. MoveGreen has also carried out air quality monitoring activities since 2017.

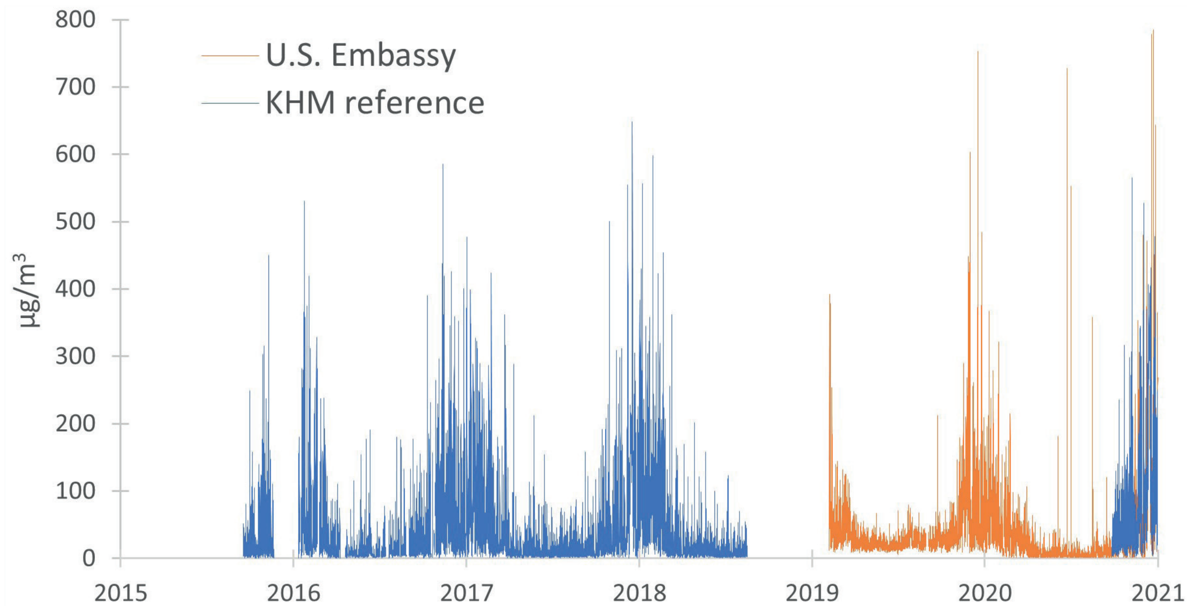


Figure 31 Hourly $PM_{2.5}$ observations at the US Embassy and KyrgyzHydromet reference site.

No data was recorded by the KyrgyzHydromet monitoring station over a long period in 2019 and 2020, so the overlapping time is too short for more detailed analysis. However, both sites highlight the air quality problems of Bishkek convincingly.

6.4 Air Quality Sensor Networks

There are many air quality sensor networks currently operating in the Bishkek area. Some of the sensor networks/operators are listed below. KyrgyzHydromet has 50 sensors in Bishkek of which 30–40 Clarity air quality sensors (https://openmap.clarity.io/) are online measuring $PM_{2.5}$. **Figure 32** shows daily average $PM_{2.5}$ concentration during 22.12.2020-7.11.2021. The different colors represent the different air quality sensors. The black bold line is the US Embassy $PM_{2.5}$ analyzer shown for comparison. These sensors show that the concentration reached extremely high daily mean $PM_{2.5}$ concentration levels (near to 1000 µg/m^3) during wintertime and the concentration decreased by the end of the heating season (February-March 2021). It seems that the sensors detected when the concentrations rose, but the absolute concentration levels vary strongly between the sensors. One reason for this can be the different locations of the sensors and local emission sources impacting strongly to the measured concentrations.

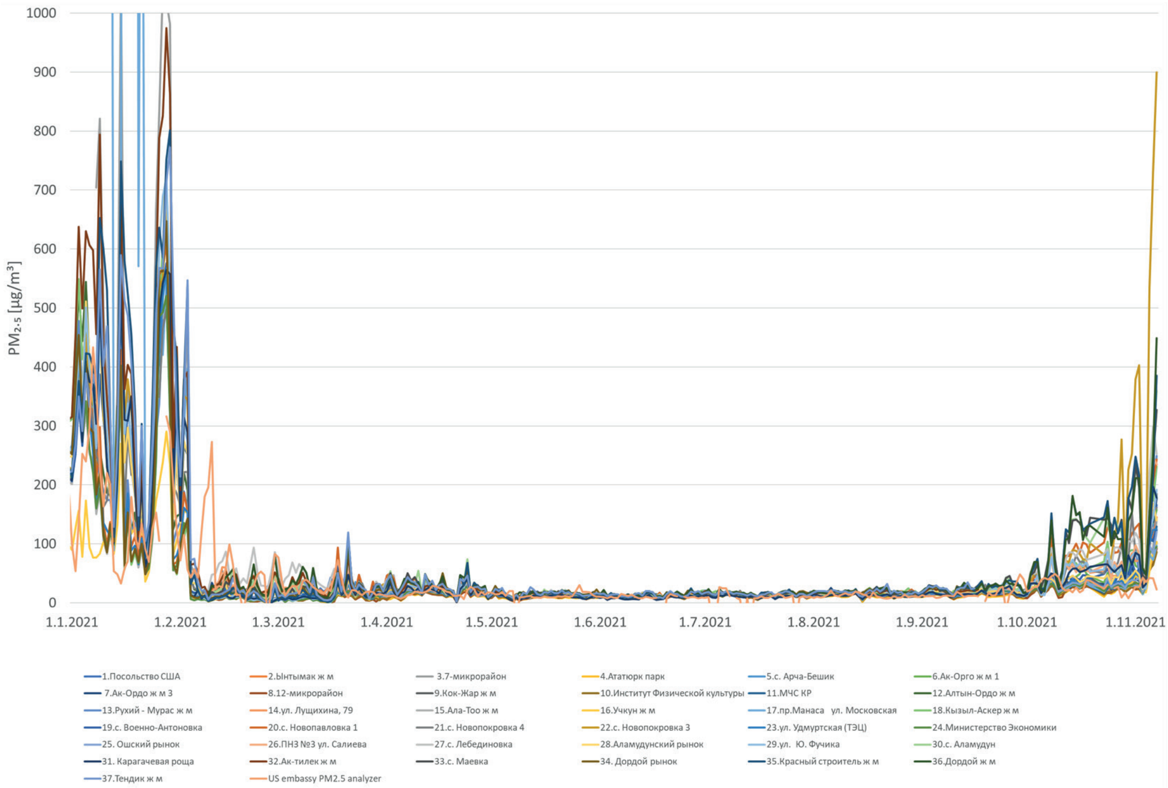


Figure 32 Daily average $PM_{2.5}$ concentration based on data from Clarity air quality sensors in Bishkek.

Figure 33 represents the spatial distribution of $PM_{2.5}$ concentration in Bishkek based on data from Clarity sensors during a seven-month period (16.2.-16.9.2021). It seems that the concentrations are lower in the Southern and Eastern parts of Bishkek compared to the Western and Northern parts of the city outside of the heating season.

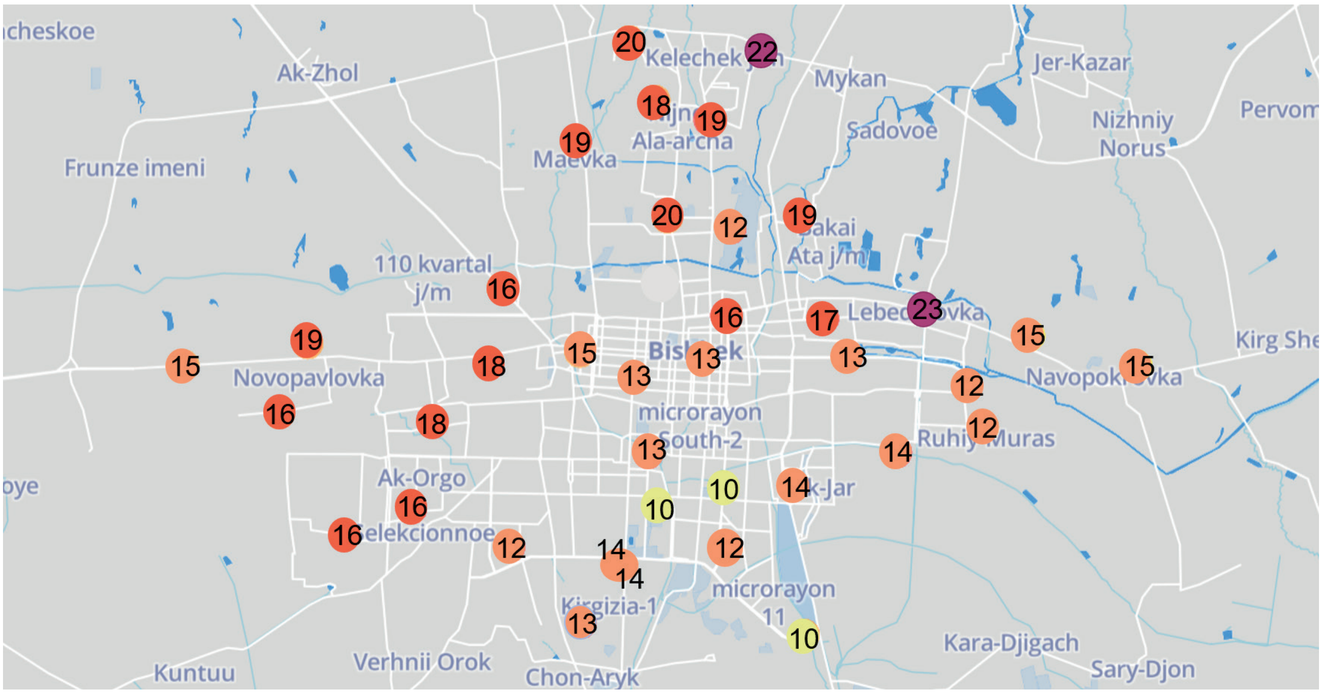


Figure 33 Spatial distribution of PM$_{2.5}$ concentration in Bishkek based on data from Clarity sensors during a seven-month period (16.2.-16.9.2021).

Data from the MoveGreen PM$_{2.5}$ sensors are also available in real-time online (https://aq.kg/). This web-page includes online information of over 50 air quality sensors by two institutions KyrgyzHydromet and Institute of Environmental Solutions. KyrgyzHydromet sensors are Clarity sensors (**Figure 34**). **Figure 35** shows daily average PM$_{2.5}$ concentration based on data from 11 AirKaz sensors in Bishkek. Location of the sensors on map are shown in **Figure 36.** The sensors were not operating all the time and thus there were some data coverage problems due to poor wifi connectivity and electricity problems.

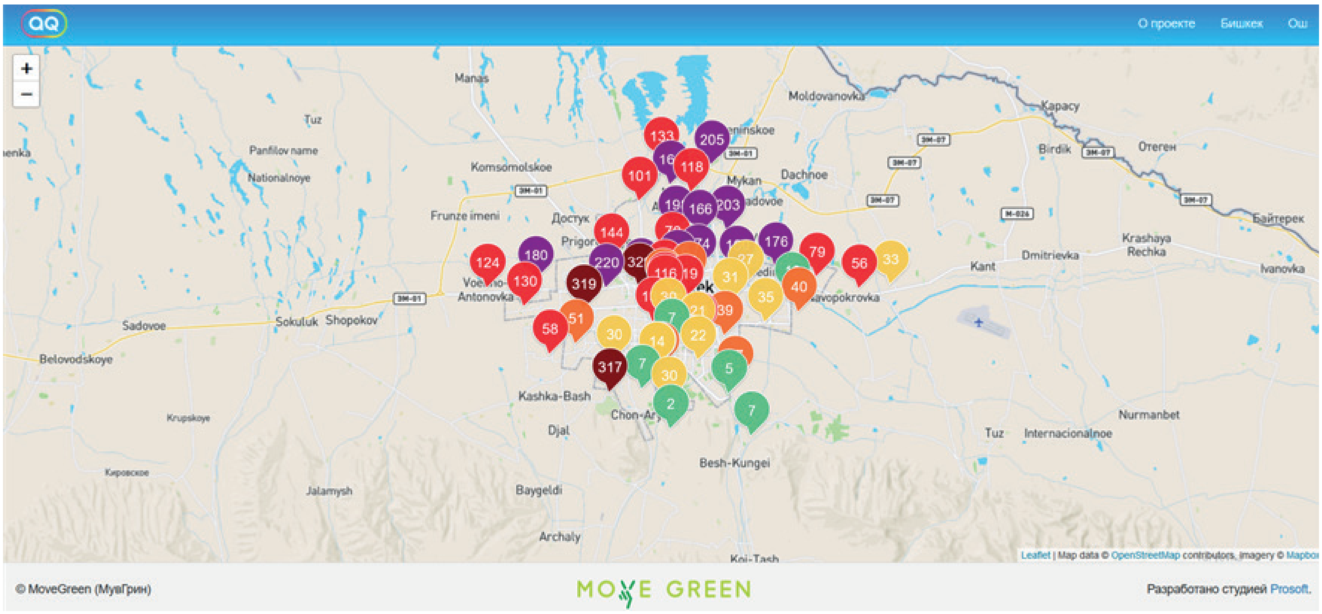


Figure 34 Movegreen air quality sensor portal/webpage with the sensor data from KyrgyzHydromet and Institute of Environmental Solutions (https://aq.kg/).

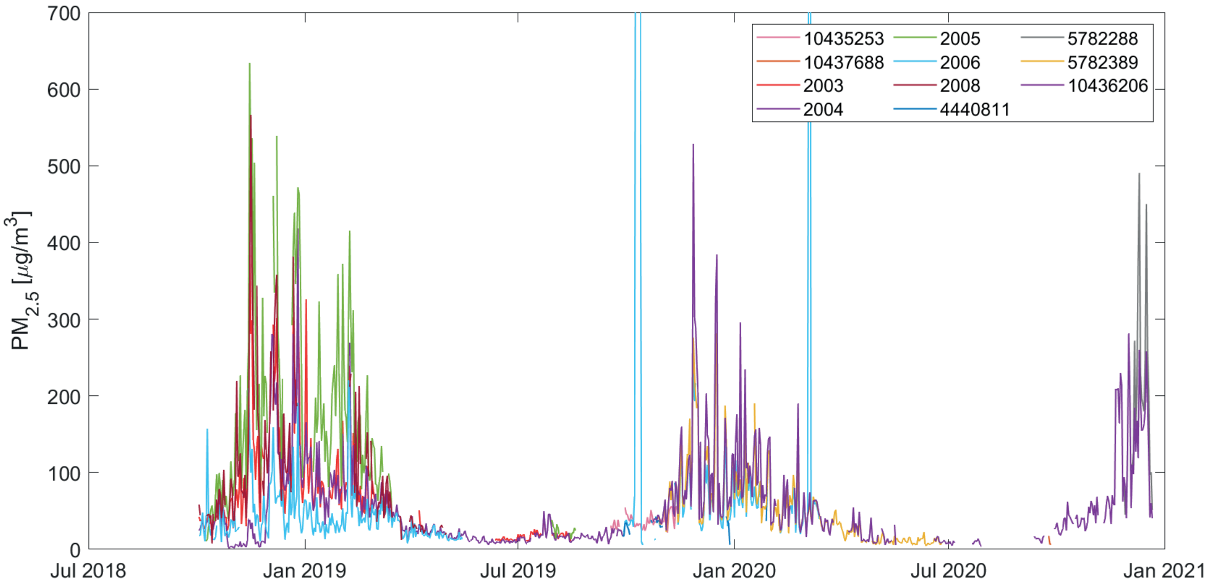


Figure 35 Daily average $PM_{2.5}$ concentration based on data from AirKaz air quality sensors in Bishkek.

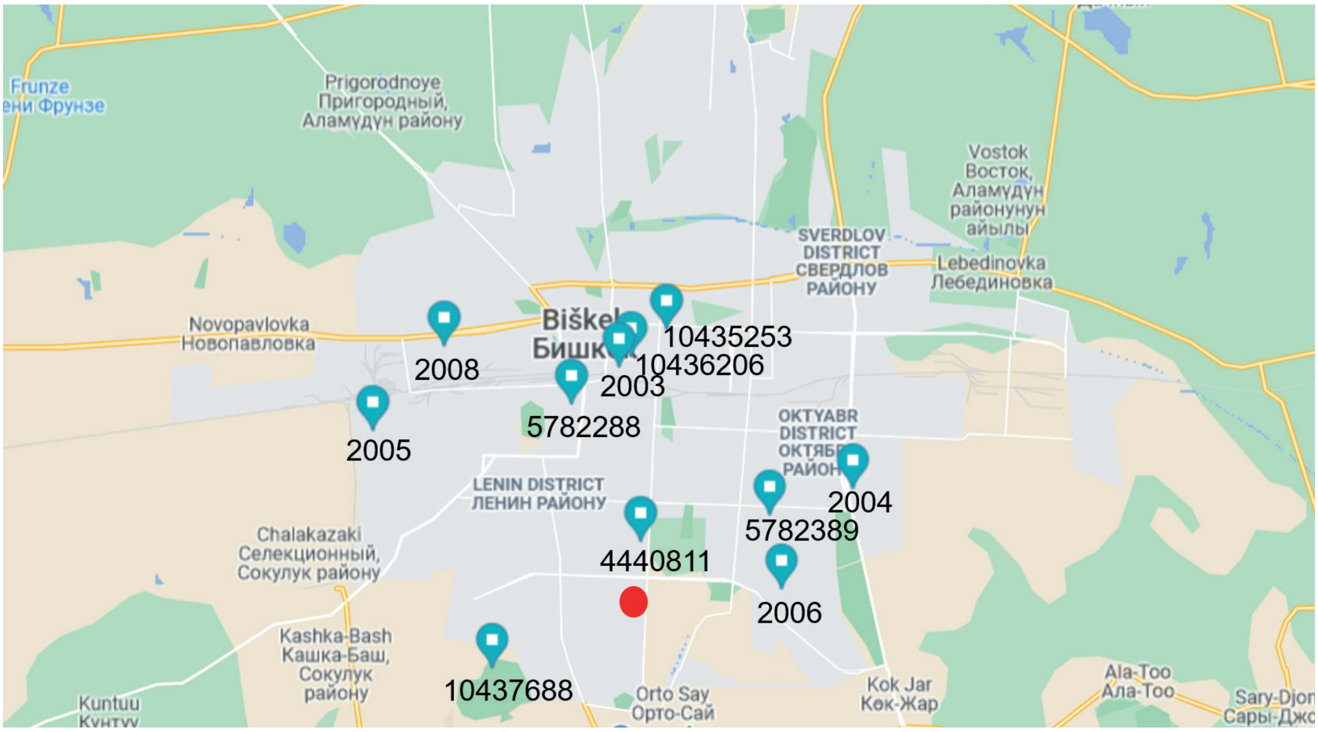


Figure 36 Location of the AirKaz air quality sensors in Bishkek.

Yearly data coverage of the AirKaz sensors is shown in **Table 10.** There seemed to be serious data coverage problems with many of the sensors, thus if the data coverage is very low (less than 75 per cent) the reliable evaluation of the sensor is difficult (EU, 2015). Evaluation of the sensor is done by comparing the sensor to the reference or equivalent to reference method analyzer, thus the sensor to be evaluated should locate nearby the reference station.

Table 10 Data coverage of AirKaz air quality sensors in Bishkek.

Sensor ID	Data coverage		
	2018	**2019**	**2020**
2003	21.7 %	30.0 %	0 %
2004	23.9 %	71.4 %	0 %
2005	16.3 %	19.4 %	0 %
2006	17.9 %	49.7 %	14.3 %
2008	14.7 %	9.3 %	0 %
4440811	0 %	3.8 %	0.3 %
5782288	0 %	0.02 %	4.9 %
5782389	0 %	17.5 %	45.0 %
10435253	0 %	13.8 %	0 %
10436206	0 %	17.0 %	54.4 %
10437688	0 %	0.02 %	0.5 %

7 SATELLITE-BASED OBSERVATIONS

Satellites provide global observations of multiple climate and environmental relevant parameters of the atmosphere, land, and ocean. One of the major advantages is that satellites provide observations over areas where there are no ground observations available, or where the measurement network is sparse. Satellite measurements also facilitate the creation of long time series, and often several parameters can be observed at the same time. This is particularly useful for the case of Bishkek, where long time series do not exist, and where the measurement network has, until very recently, been very sparse.

Passive satellite instruments measure reflected radiation at selected wavelengths (**Figure 37**). The key is the "fingerprint" that different gasses and aerosols leave on the radiation measured. By selecting different wavelength channels, different gasses or aerosols can be measured.

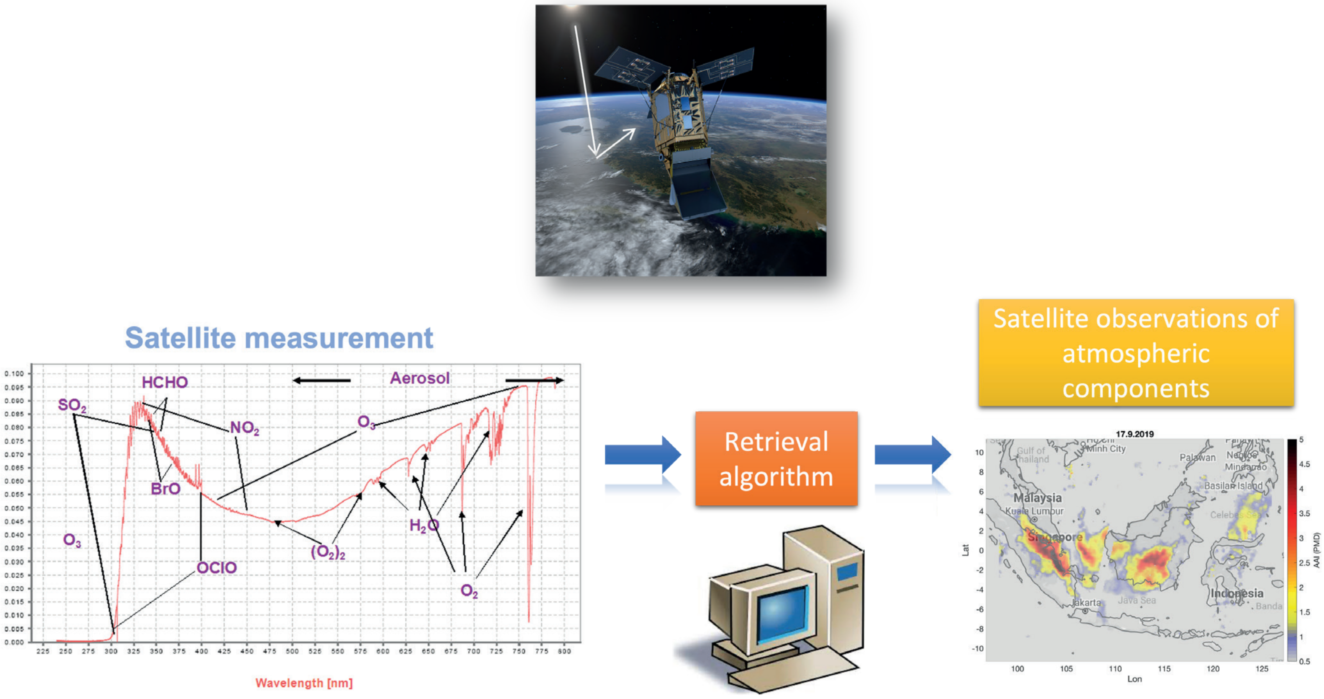


Figure 37 Basic principle of a passive satellite measurement.

7.1 Satellite-based NO_2 Observations

Nitrogen dioxide (NO_2) is an important air pollutant that is mainly released from combustion engines and energy production (burning of fossil fuel). Its concentrations are thus typically elevated near large population centers such as cities. Its concentrations also correlate well with those of other air pollutants released from the same sources, especially fine particles (Touloumi et al., 1997; WHO, 2021a), so it can be used as a general indicator for air quality in areas of poor air quality.

Figure 38 and 39 show variation of tropospheric NO_2 in Bishkek. The NO_2 concentrations show a slightly increasing trend from 2005 until 2020. However, the concentration level has remained the same for about 10 years. The concentrations in winter months are higher than during summer-months, probably due to the meteorological conditions.

Figure 40 shows the satellite-based tropospheric NO_2 column concentrations over Bishkek, Kyrgyzstan and the area of neighboring countries nearby. Over mountainous areas satellite observations are typically highly uncertain, but the NO_2 levels are anyway very low due to lack of relevant emissions. In wintertime (February 2020 as example year) the NO_2 concentrations are higher and the areas with high concentrations are bigger than during summertime. This is most likely due to the meteorological and topographical conditions as the highest concentration areas in the region (the scale at which the satellite data represents) are located in lower altitude areas (i.e. in valleys) in Uzbekistan, Bishkek and Almaty.

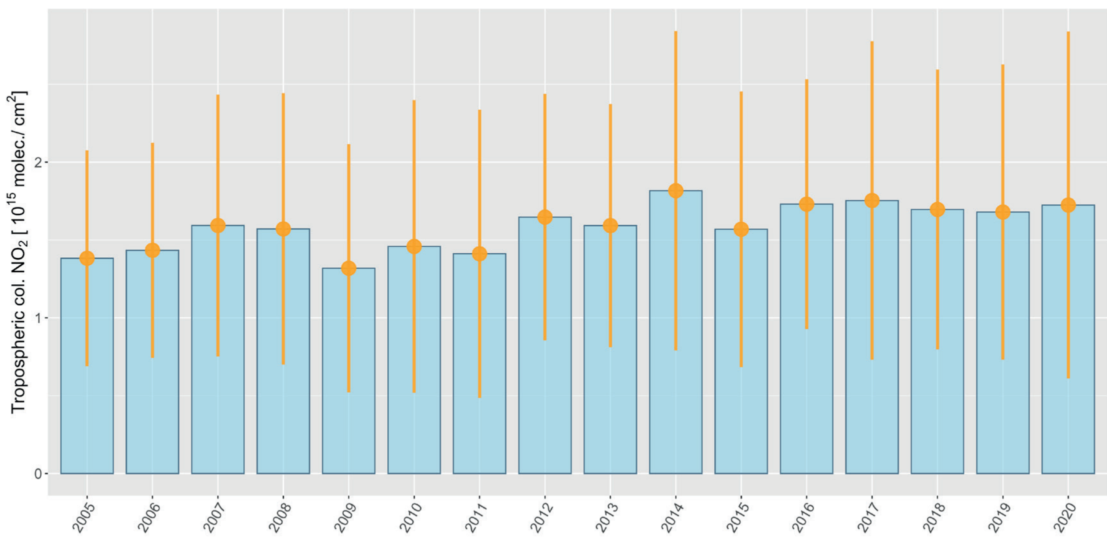


Figure 38 Annual mean NO_2 concentrations in Bishkek for 2005-2020 from the OMI instrument.

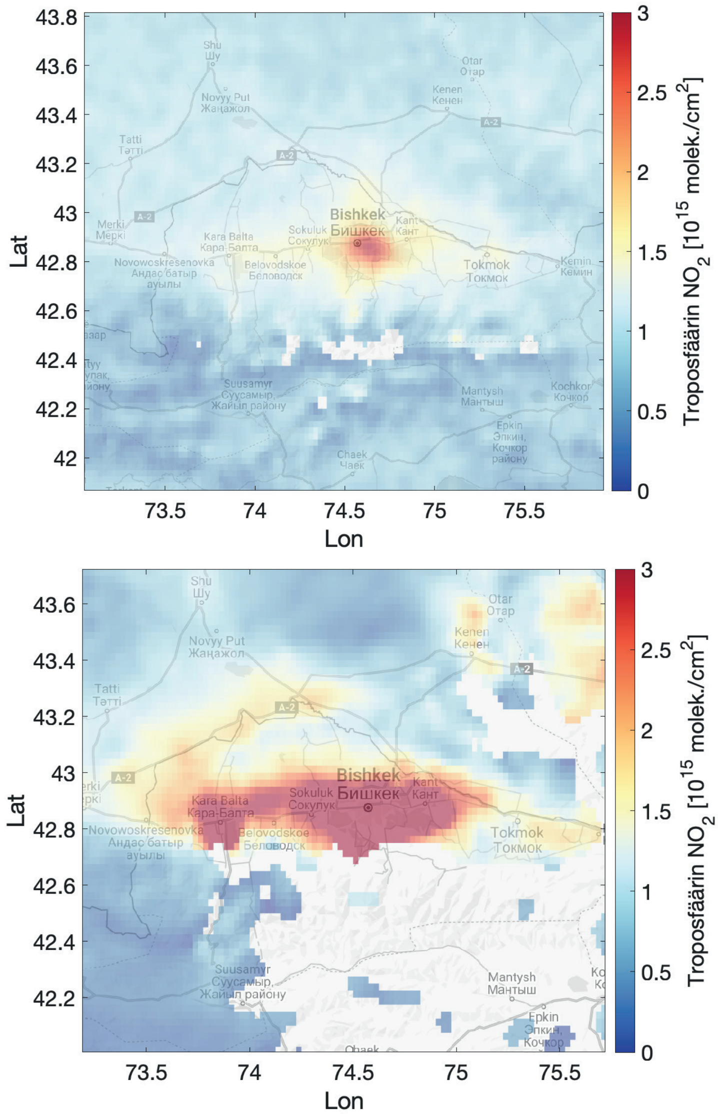


Figure 39 Monthly mean tropospheric NO_2 in Bishkek from the OMI (Ozone Monitoring Instrument) instrument, upper figure represents July 2020, and lower figure February 2020.

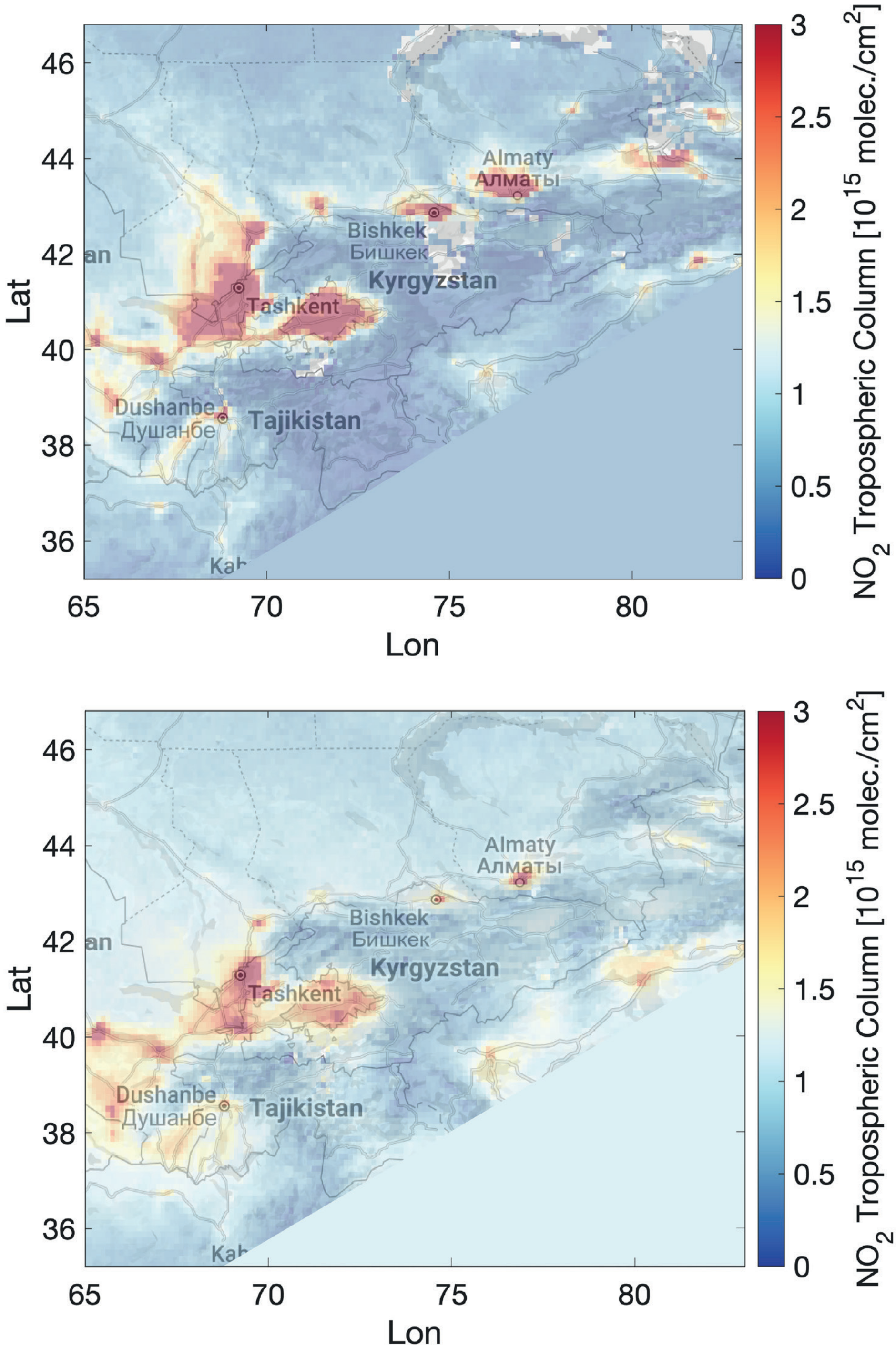


Figure 40 Spatial variation of tropospheric NO_2 in Kyrgyzstan (TROPOMI-instrument (TROPOspheric Monitoring Instrument)), Feb. 2020 and July 2020).

7.2 Satellite-based SO_2 Observations

From satellite data no major sulphur dioxide (SO_2) emission sources have been identified over Kyrgyzstan (**Figure 41**). According to satellite data, the overall SO_2 is very low in Bishkek and Kyrgyzstan. According to ground level air quality monitoring data the SO_2 concentrations in Bishkek are very high particularly during wintertime. Thus, it seems that satellites are not able to see the SO_2 emissions in Bishkek. The reason for this might be that the SO_2 emissions are not released from one emission source but many small sources in the area. Typically, major oil production fields in the Arabian Peninsula, oil refineries or big smelters with high SO_2 emissions can be seen in the satellite data.

Map shows the locations of identified emission sources (i.e. where satellite signals are strong enough) in the neighboring countries. The SO_2 emission source must be very big and strong so that satellites can identify it. For example, emissions from fugitive sources like household burning/heating, can be very difficult to locate with the satellite data and are generally too low and scattered to be detected.

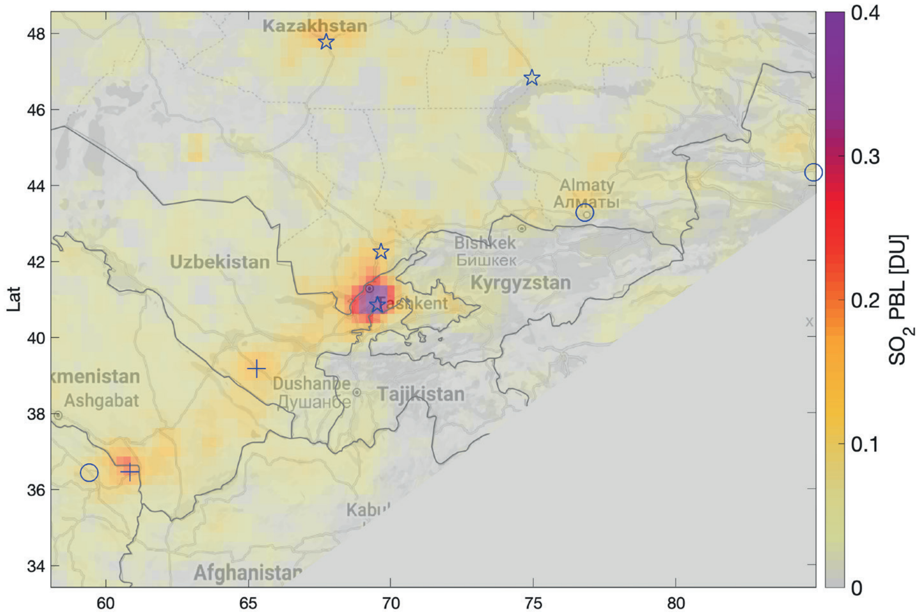


Figure 41 SO_2 total column concentration from the OMI instrument, annual mean 2019.

7.3 Aerosol Observations by Satellites

Satellite-based Aerosol Optical Depth (AOD) describes the aerosol extinction in an atmospheric column. AOD is highly related to the number of aerosols, and hence, even though the definition of AOD is very different from the Particulate Matter (PM) concentrations, the two quantities typically correlate well. It should be noted that AOD is very sensitive to clouds, and thus observations cannot be obtained when clouds are present. However, when averaging over a longer time (**Figure 42** and **43**), satellite-based AOD is a useful parameter for estimating the spatial distribution of aerosols and emission sources, especially over areas where the ground-based sensor network is sparse or absent.

Currently satellite-based AOD observations are available from multiple instruments. In this report the AOD maps are averages from two MODIS instruments onboard NASA's Terra and Aqua satellites. Both satellites provide observations over a certain area once per day, Terra before noon at about 10:30 local time, and Aqua in the afternoon, at about 13:30 local time, which excludes the time of the day when particulate matter concentrations are the highest in Bishkek, the highest peak is in evening after 18:00 (**Figure 26**). In this analysis the AOD maps are defined from daily means of Terra and Aqua observations. The MODIS instruments can also provide information on active fires and burned areas.

AOD (or AOT) describes the extinction of solar light caused by aerosols in an atmospheric column. AOD is related to the number of aerosols, typically it varies (at 550 nm wavelength) between 0.1 and 1.0. AOD often has a similar variation to $PM_{2.5}$ and/or PM_{10} (although it is not the same parameter).

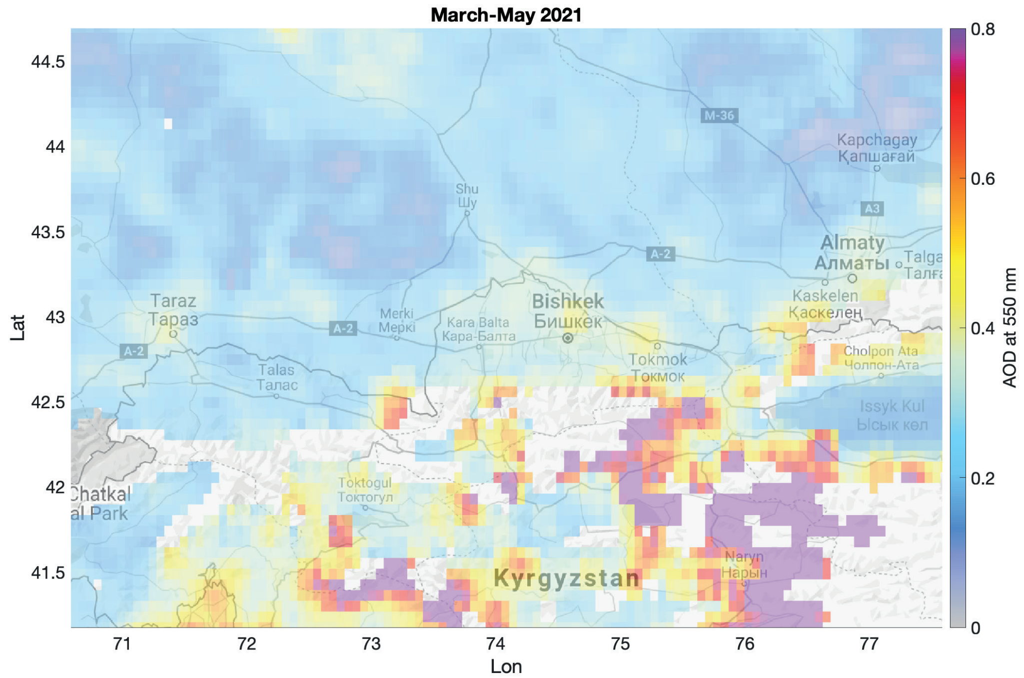


Figure 42 Aerosol optical depth from the MODIS instruments. Spatial variation of AOD at 550 nm. Pink color illustrated dust. High uncertainties exist over the mountains.

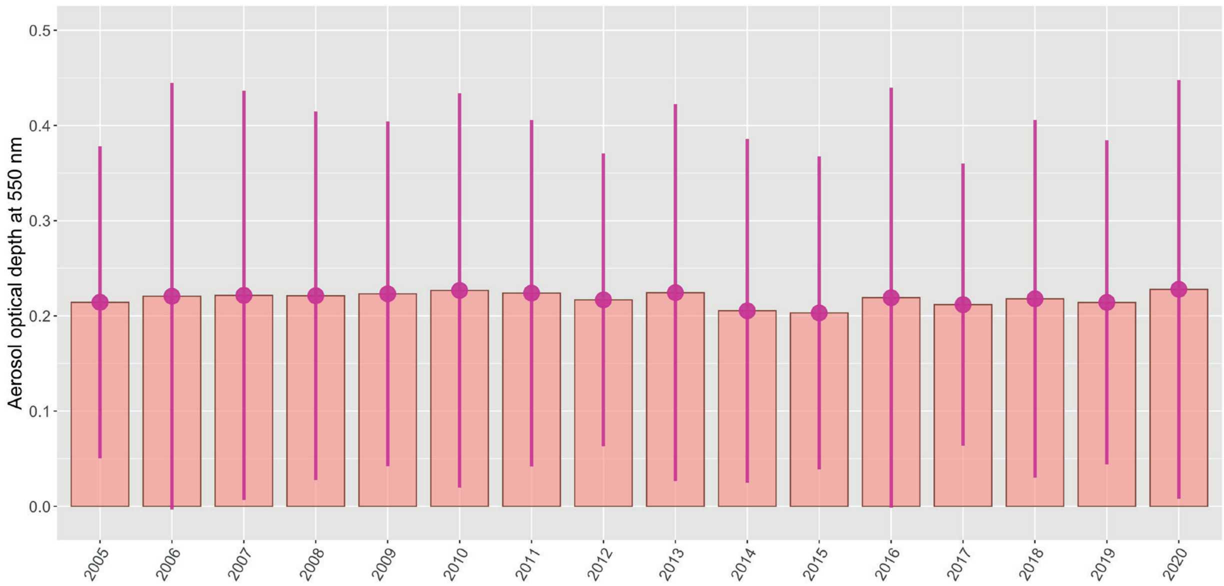


Figure 43 Long-term variation of AOD (2005-2020), annual mean, whole country, MODIS-instrument.

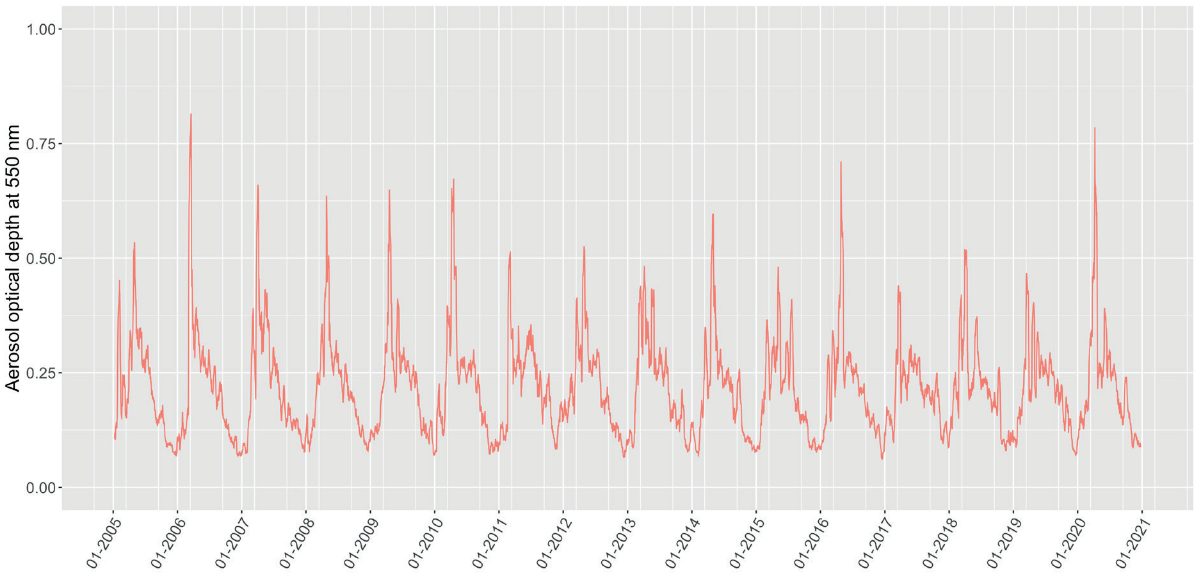


Figure 44 Long-term variation of AOD (2005–2020), Aerosol optical depth from the MODIS instruments. 15 day running means (the whole country).

8 EMISSION INVENTORY

8.1 Introduction

Emission inventories are a key component of air quality management. They are used for several different purposes. Historical emission estimates provide information on the magnitude of different sources and trends with time. They can also be used as input into dispersion models to determine concentration estimates across large areas.

Historical emission inventories can also be used for policy development and evaluation:

- **Policy development:** Developing policy requires high quality historical emission estimates which are used as a basis for projecting estimates into the future. The impacts of policies and measures on emissions in future years can then be quantified to support decision-makers in designing different future scenarios, and ultimately deciding what interventions are the most appropriate to take forward. Further, the collection of sex-disaggregated data on populations in areas under measurement helps in drawing trends and co-relations between population and gender-differentiated health outcomes. Such information is crucial for integrated policy approaches that address economic, social, and environmental constraints.

- **Policy evaluation:** Historical emission inventories can be used to monitor whether previously implemented policies and measures have successfully delivered what was originally planned. This is helpful in explaining both success and situations where policies and measures have not delivered as expected. The interconnectedness between people and planet is inextricable; therefore, the analysis of emission trends, alongside sex-disaggregated data and health data of the populace in a specific area is crucial. Integrated approaches remain key in this work as they help identify important trends that would otherwise remain hidden.

The following sections provide an explanation of the data that has been used to compile an emissions inventory for Bishkek for 2000 to 2018, as well as the emission projections from 2018 to 2040. The results of the historical emission estimates are also presented. The results of emission projections under different scenarios are presented in **Chapter 9.**

8.2 Emissions Inventory Methodologies

The following sections outline the methods used to estimate the different sources in the emissions inventory. Explanations are also included to explain where it was necessary to include assumptions or expert judgment. These were typically needed to: adapt datasets to meet the needs of the emissions inventory, address gaps in the data availability, address gaps in the knowledge of local circumstances and the specifics of emission sources.

Emissions of a pollutant from a given source are usually calculated by multiplying "activity data" by an "emission factor". Activity data is commonly the amount of fuel consumed, but it can be e.g. population, GDP or other indicators of an "amount". An emission factor represents a pollutant specific emission rate, and is usually taken from international guidance, such as the EMEP/EEA Air Pollutant Emissions Inventory Guidebook (EMEP/EEA, 2019), or the IPCC's 2006 Greenhouse Gas Emission Inventory Guidelines (IPCC, 2006).

8.3 Emission Inventory by Emission Sectors

8.3.1 Combined Heat and Power Plant and District Heating

Activity data

World Bank studies on heating systems in Bishkek provided the 2012 fuel consumption (coal, fuel oil, and natural gas) for electric power plants combined heat and power plant (CHP), district heating plant, and also large and small "heat only boilers" (HOBs) i.e. district heating units operated by Bishkekteploenergo. A fuel consumption time series was obtained by assuming that these emission sources were a constant fraction of the national fuel used in electricity and heat generation (as given the national fuel balance tables for 1999, 2005-2018). It was necessary to make several assumptions about net calorific values of fuels in the calculations, but this was guided by local knowledge and information from international guidance material. Interpolation was used for 2000-2004, and extrapolation was used for 2019-2030 (rescaling by predicted population).

This represents a relatively simple approach for determining the annual fuel consumption from these major sources and obtaining actual fuel consumption data (or emissions) from each of the units would be a significant improvement. No information was obtained on fuel use in fuel refineries in Bishkek, so it is assumed that there are no relevant activities.

Emission factors

Kyrgyzstan has reported emissions from point sources to the CLRTAP for specific years (see https://www.ceip.at/status-of-reporting-and-review-results), and submissions in 2016 and 2021 include emission estimates for CHP (see Kyrgyzstan's Annex IV files available from https://www.ceip.at). It was therefore possible to make some relatively well supported assumptions about the most appropriate emission factors to use from the ranges presented in the EMEP/EEA Guidebook (EMEP/EEA, 2019) for electricity generating stations. Emission factors for HOBs were also selected from ranges presented in the EMEP/EEA Guidebook (EMEP/EEA, 2019) by drawing on the limited available information on the sources and how they are operated.

8.3.2 Industrial Combustion

It is not known whether this is a large source in Bishkek or not. Potential sources include everything from large heavy industry plant, down to small businesses — but the only known large industrial plant in the region are outside the Bishkek city limits.

National energy balance tables, available from the National Statistical Committee of the Kyrgyz Republic's website provide 2006-2015 fuel consumption data for "Manufacturing" and "Construction, installation and drilling works". These were rescaled to give data for Bishkek by using gross regional product data. Data for years after 2015 were generated by assuming a simple 3 per cent annual growth in fuel consumption - an expert judgment based on: growth in recent years, global economic forecasts from international organisations, and expected improvements in fuel efficiency.

Default emission factors were taken from the EMEP/EEA Guidebook (EMEP/EEA, 2019).

8.3.3 Residential and Commercial/Institutional Combustion

This source category is one of the largest emission sources in the emissions inventory, and consequently priority was given to sourcing detailed information to help characterise this source to the best extent possible. However, no relevant information was available on the fuel used in commercial/institutional buildings, and it has been assumed that this is included in the (much larger) residential fuel use statistics. So, emissions from commercial/institutional buildings are not thought to be omitted from the emissions inventory, but they are not resolved from residential emissions.

The emission calculations were made at a detailed resolution, splitting out the emissions from different types of domestic appliance. This does not improve the accuracy per se, which is limited by the quality of the input data, but it does allow the impact of a range of different policies and measures to be assessed, which is expected to be important in supporting policy development.

Activity data

Emission calculations for this source sector were linked to those for electricity and heat production. This is because some houses use heat provided centrally from CHP or district heating plants, and others rely on residential stoves and boilers, using a range of different fuels.

The number of households using coal as a primary fuel was obtained by drawing on data from recent World Bank studies (World Bank, 2015; 2020). This also gives an indication of the different types of appliances that are in use, and the percentage contribution that each makes to the total number of appliances.

The number of households without access to district heating and using coal as their primary fuel was determined as the difference between the households in the city and those on the district heating network. The annual coal consumption per household is detailed in World Bank reports (World Bank, 2015; 2020), split by appliance type, and the "average" values were used.

Combining the number of households with the annual fuel consumption per household (split by appliance type) gave estimates of the coal consumption in 2015 split into conventional stoves and small boilers. This was extended to all of the historical time series by assuming that the fraction of the national fuel use remained constant (and using interpolation for 2000-2004). Estimates for 2019-2030 were made by extrapolation, scaling by population.

Local counterparts considered that the use of rubbish as a fuel is significant in Bishkek. It was not possible to make an estimate of the amount that was being burned in heating appliances, and consequently no emission estimates have been included in the emissions inventory. However, emissions from the open burning of waste are included in the emissions inventory in the waste sector (see below).

Emission factors

Default emission factors for conventional stoves and small boilers have been taken from the EMEP/EEA Guidebook (EMEP/EEA, 2019). However, as emissions from this source sector are expected to be large, it will be important to try to obtain more detailed information on the use of different appliance types as possible, as these have a significant impact on the resulting emissions.

8.3.4 Road Transport

This is one of the larger sources, and one that is likely to be subjected to several different policies and measures. It is therefore important to use detailed data to calculate emission estimates that can represent the impacts of different policies and measures.

Emissions depend very much on the abatement technologies that are installed in the different types of vehicles, with older vehicles being generally much more polluting. So, as well as considering petrol and diesel vehicles separately, the main vehicle categories (passenger cars, light commercial vehicles, heavy duty vehicles, and motorcycles and mopeds) were sub-divided into different technologies according to emission control legislation.

Resuspension of road dust is not typically included in emission inventories, and no emission estimates were made. But it should be considered as an item for future development of the emissions inventory.

Activity data

National consumption of petrol and diesel in road vehicles was obtained from publicly available national statistics, for 1999, 2005-2018, taken from national energy balance tables, available from the National Statistical Committee of the Kyrgyz Republic (http://www.stat.kg/en/). Interpolation was used to estimate the fuel used in 2000-2004. Fuel used in future years was estimated by assuming that the trend of increasing fuel consumption across 2005-2018 continues to 2030, but at a reduced rate. The national annual petrol consumption was combined with publicly available data on "passengers carried by automobile" for Bishkek and at the national level to estimate a petrol total for Bishkek (data also available from the National Statistical Committee website). It was assumed that this petrol is only used in passenger cars, as there was no information available to allocate it to other road vehicle types.

The national annual diesel consumption was combined with publicly available data on road freight and passengers carried by public transport for Bishkek and at the national level. This allowed estimates for the diesel used in Bishkek by road freight and for public transport to be estimated. The diesel allocated to public transport was then split into annual fuel use in minibuses and (large) buses by taking into account the number of minibuses and buses as well as the corresponding fuel economy. No information was available on the amount of diesel used by cars, so expert judgement was made after consultation with local counterparts on the fraction of the total diesel that is used in cars.

This method of allocating the diesel to different vehicle types requires several significant assumptions, and a high priority improvement task is to obtain data that provides a much more robust representation of the fuel used in the road transport sector in Bishkek to deliver improved emission estimates.

National data for the annual use of LPG in road vehicles is available from national energy balance tables. It was assumed that this is all used in Bishkek. This is expected to be an overestimate but was considered to be a better approach that rescaling the data to potentially result in unrepresentative information. The emissions arising from the use of LPG are extremely small when compared to petrol and diesel consumption.

Emission factors

Mandatory emission control had been canceled in 2012. Since that, there are some regulations for the vehicles used in registered businesses, and special machinery (lorries, trucks, etc.). Technical inspection/ emission control for other vehicles is on a voluntary basis.

The EMEP/EEA Guidebook (EMEP/EEA, 2019) provides an aggregated emission factor that is intended to represent the mixture of ages and technologies in petrol cars in "newly independent states" (which includes Kyrgyzstan). However, information from local counterparts supported the assumption that a high portion of the cars have had their catalytic converter removed because local fuel quality stops them from working properly, and because the catalysts have a market value. So, it was assumed that 95 per cent of the petrol cars were pre-Euro 1 (either because they are old or have had the catalytic converter removed), with the remaining 5 per cent being Euro 4. Diesel cars were assumed to all be pre-Euro 1, and LPG cars were assumed to be pre-Euro 4.

The emission factors for "newly independent states", from the EMEP/EEA Guidebook (EMEP/EEA, 2019), were used for light commercial vehicles (representing minibuses and vans), buses and heavy-duty vehicles.

These emission factors are thought to provide a reasonable representation of the road transport fleet in Bishkek. However, it would be much better to obtain local data. Importantly, the current assumptions do not take into account the changes in the vehicle fleet across the time series. This will be a key improvement to incorporate into future versions of the emissions inventory.

8.3.5 Other Transport and Mobile Machinery

This sector includes emissions from several sources categories:

Aviation, rail, and mobile machinery

Bishkek airport is outside the geographical scope of the study, and emission estimates have not been calculated. The influence of these emissions on concentrations in the city is expected to be very small as the annual number of take-off/landings is small compared to other international airports.

Local counterparts suggested that there is only one line between Issyk-Kul lake and the Kazak border through Bishkek, and the rail line supplying the CHP. No information has yet been obtained on diesel use for railway locomotives in Bishkek. It is likely that it is relatively small, and that diesel used in the rail sector has been allocated to road freight, but it will only be possible to improve the resolution of the current emission estimates if detailed fuel use data in both road and rail can be obtained.

Mobile machinery includes a wide range of different machinery types – generators, compressors, construction machinery, aircraft support vehicles, and other specialist machinery and equipment. Currently, diesel consumption in Bishkek is assigned to stationary combustion and road vehicles. If more detailed data becomes available then it may be possible to allocate an appropriate portion of fuel consumption to mobile machinery, but this is a particularly challenging source to accurately represent in emission inventories.

8.3.6 Fugitive Emissions, Industrial Processes and Product Use

Fugitive emissions

Fugitive emissions are the accidental release of pollutants, primarily from the manufacture and distribution of fossil fuels. So, sources include emissions from the oil and gas sector (during exploration and extraction), leaks from gas distribution pipelines, and evaporative losses during distribution of fuel to petrol stations — almost exclusively for NMVOC.

It has not been possible to source any relevant activity data, so there are currently no emission estimates for fugitive emissions in the emissions inventory.

Industrial processes

Industrial processes cover a wide range of different types of sources. It includes process emissions from mineral products (including cement production), the chemical industry, metal production, solvent use, pulp and paper production and wood processing, and the food and beverage industry. The collection of data disaggregated by sex in various industries that emit pollutions is crucial. Research shows that men are more likely to be exposed by occupational pollution as they are more likely to work in industrial sites. The impact of pollution also varies for men and women and thus the collection of this data is crucial towards the formulation of integrated, gender-responsive policies.

Data has been obtained on annual food and beverage manufacture in Kyrgyzstan from the National Statistical Committee (http://www.stat.kg/en/). The annual production quantities of selected food and drinks were rescaled by gross regional product statistics, also available from the National Statistical Committee, to give a figure for Bishkek. Combining these with default emission factors from the EMEP/EEA Guidebook (EMEP/EEA, 2019) gave corresponding emission estimates.

Product use emission

Product use emissions are usually dominated by NMVOCs from products that contain solvents, such as paints, cosmetics and pharmaceuticals.

It has only been possible to estimate emissions from domestic solvent use, which are based on annual population data. Industrial solvent use should also be considered for the emissions inventory, although it is often challenging to obtain relevant data for emission factors.

8.3.7 Agriculture

It has been assumed that there are no agricultural sources in Bishkek.

8.3.8 Waste Management

This sector includes emissions from landfill, the treatment of wastewater, open burning of waste, and waste incinerators with no electricity/heat generation. Sources in waste management are usually smaller than other source sectors and are therefore generally of lower priority in urban emissions inventories.

Landfill

Bishkek landfill is outside of the geographical scope of the study. However, it was not known whether emissions from the landfill fire impact on air quality in the city, so emission estimates were made (see **Waste burning** below). Emissions from the landfill activities itself ($PM_{2.5}$ emissions from waste handling, and NMVOC from waste decomposition) were not made due to a lack of input data.

Domestic wastewater treatment

Wastewater handling is typically an insignificant source of air pollutants, and estimates have not been included in the inventory.

Waste burning

Incinerators

The presence of a hospital in Bishkek suggests that there is likely to be a clinical waste incinerator (although waste may be treated by an autoclave/steriliser for subsequent disposal at a municipal landfill site). As no activity or emissions information was available, emissions data from several clinical waste incinerators in the United Kingdom were compiled, and expert judgment was used to determine emission estimates considered to be representative for Bishkek. This is a rough approximation only but provides an initial emission estimate that can be improved on.

Open burning of waste

Open burning of waste and the fire at the landfill are included in this source category.

The open burning of waste is a common practice in gardens and yards in Bishkek. Best estimates were made about the frequency and size of these fires to give an annual average amount of waste burned per household. This was then multiplied by the number of households in the city to obtain an estimate of the total amount of waste burned. Default emission factors for open burning of waste were taken from the EMEP/EEA Guidebook, to give emission estimates.

There is a continuous uncontrolled fire at Bishkek's landfill, and this is releasing pollutant emissions into the air. Whilst the landfill is outside the city, it was considered appropriate to make emission estimates for information, and not include them in the emission inventory totals. The length of the fire front can be estimated from satellite images as being 100m. Best estimates were then made about the annual amount of waste material being burned for each meter of fire, and the total was combined with emission factors for open burning of waste from the EMEP/EEA Guidebook (EMEP/EEA, 2019). The resulting emissions from the landfill fire are relatively small when compared to other sources in Bishkek. Given the impact that the fire is reported to have on localized air quality, it may be that emissions are underestimated by the current assumptions and simple methodology.

Estimates of emissions in the waste sector currently rely on best estimates and a number of assumptions. They are therefore very high in uncertainty. Improvements could be made by obtaining local data on the amount of waste burning that occurs in Bishkek.

8.4 Historical Emission Estimates and Emission Projections

Output from the emissions inventory is shown in the following sections. However, as noted in the methodology sections above, there are significant shortcomings with the input data that was available, and as a result the outputs are not of high quality. The input data needs to be more detailed, complete and accurate to provide emission estimates that are sufficiently reliable. The current outputs do provide a useful indication of the relative importance of different sources, and the historical trends, but it is important not to over interpret the data.

Emissions are also shown for future years, i.e. emission projections. The emission projections shown in the figures in this chapter are based on the "with measures" projection. This assumes the continuation of existing policies and measures (and the introduction in future years of policies and measures that have already been clearly committed to). It represents a scenario that is often loosely termed "business as usual".

A range of different future scenarios can be created by adding in different combinations of new, or "additional" policies and measures. This is done to assess the potential impact on emissions of the additional policies and measures. Three "with additional measures" scenarios are considered in **Chapter 9.**

8.4.1 Quality of the Emissions Inventory

Standard quality metrics exist to assess the quality of an emissions inventory (EMEP/EEA, 2019). These are: Transparency, Completeness, Consistency, Comparability and Accuracy. The inventory that has been prepared for Bishkek is based on very limited input data, and there were a number of challenges encountered:

The most significant challenge was the lack of Bishkek specific data to support historical emission calculations across the different sources. National datasets had to be converted to Bishkek level data, data gaps had to be filled by making broad assumptions, and an extensive amount of expert judgment (either from international experience, or anecdotal information from local counterparts) had to be used in place of data.

The detail level of the data also caused issues in some historical emission calculations. As a result, relatively simple calculation methodologies have been used. Whilst these can provide a good representation of the real-world emissions, they often do not take into account variations that might arise from key underlying variables. For example, in the road transport sector there was only enough information to undertake a relatively simple calculation based on the fuel use. However, in an attempt to support policy development, annual emissions were calculated by vehicle type and by technology. This required assumptions to be made about the age of the vehicle fleet and emission control technologies in use but allows the impact of potential policies and measures to control emissions to be quantified. So, it is important that the detail levels to which the emissions inventory sources are presented is not interpreted as an indication of the level of accuracy of the emission estimates.

Emission projections are also included in the plots below. In addition to the uncertainties associated with the historical emissions estimates, the projections include additional uncertainties created by projecting these historical emission estimates into future years. The future trends included in the inventory are relatively simple, and the majority are based either on the growth in population or GDP, taken from publicly available information from the National Statistical Committee (http://www.stat.kg/en/). The impacts of various policies and measures are considered in **Chapter 9**, which presents projections under scenarios of differing ambition level.

Priority emissions inventory improvements and key shortcomings are considered in **Chapter 8.4.7** below.

8.4.2 Nitrogen Oxides (NO_x)

Emissions of NO_x are dominated by road transport, and petrol cars in particular. Heavy duty vehicles (lorries) also make a large contribution to total NO_x emissions.

The predicted growth in the vehicle kms driven is reflected in the increased emissions in future years. The forecast shown below in **Figure 45** assumes that there is no modernisation of the vehicle fleet. However, NO_x emissions from a car without a catalytic convertor can be 50 times higher than one with a catalytic convertor. So even a gradual modernisation of the car fleet would have a very large impact on total emissions. The increased use of electric vehicles would also have the potential to make a substantial reduction in future emissions. This is also the case for heavy duty vehicles, where a lorry with no emissions control can emit 30 times more than one using modern emissions control technologies. Ensuring that the vehicle fleet is accurately represented in the emissions inventory is therefore not only important in calculating historical emissions, but also in supporting the development of policies that address air quality issues. Emissions from the CHP make a small contribution to the total.

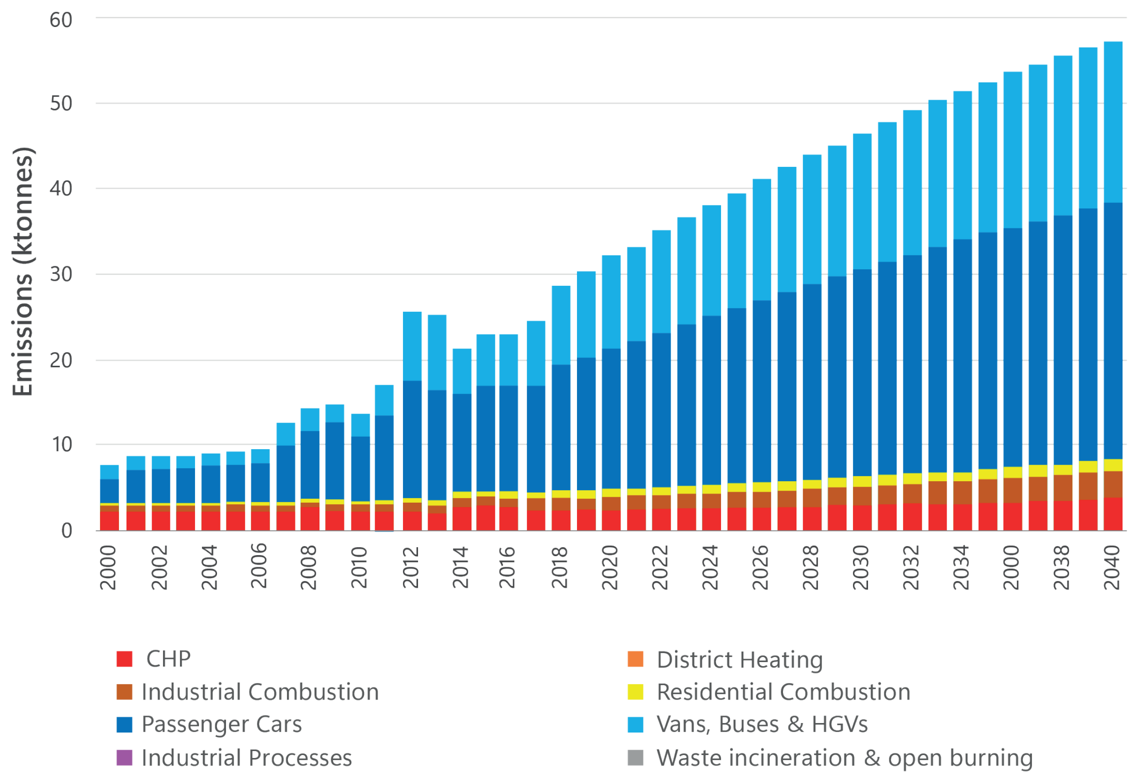


Figure 45 NO_x emissions (With Measures scenario).

8.4.3 Particulate Matter ($PM_{2.5}$)

Emissions of particulate matter, and more specifically $PM_{2.5}$, arise from a number of different sources. Road transport makes a large contribution to the total emission, but residential combustion is the largest source by a significant margin (**Figure 46**).

Residential emissions are dominated by the use of coal in very simple stoves and boilers. These generally operate with inefficient combustion conditions compared to more modern heating appliances, and coal is a fuel that gives rise to relatively high $PM_{2.5}$ emissions compared to other fuels. Changing from a convention stove to an advanced stove can reduce emissions by approximately 30 per cent. Whilst this is a significant reduction, the extent to which current $PM_{2.5}$ concentrations are above recommended health-derived limit values means that it is unlikely that this change alone would be sufficient to address the high $PM_{2.5}$ concentrations in the city. Whilst no detailed studies have been undertaken, it is expected that other policies and measures would be needed, such as investment in home insulation, fuel switching away from coal etc. and policies that affect other source categories.

Emissions from road transport grow in importance in future years because the emissions are forecast to grow faster than those from the residential sector. Changing from an old lorry to one with new emissions control equipment can reduce emissions by a factor of more than 100. So, modernisation of the fleet to vehicles that include diesel particulate filters has the potential to have a big impact in controlling $PM_{2.5}$ emissions.

Emissions from industrial combustion are predicted to become increasingly important in future years. Moving away from coal as a fuel would make a large contribution to controlling emissions, as would the modernisation of boilers.

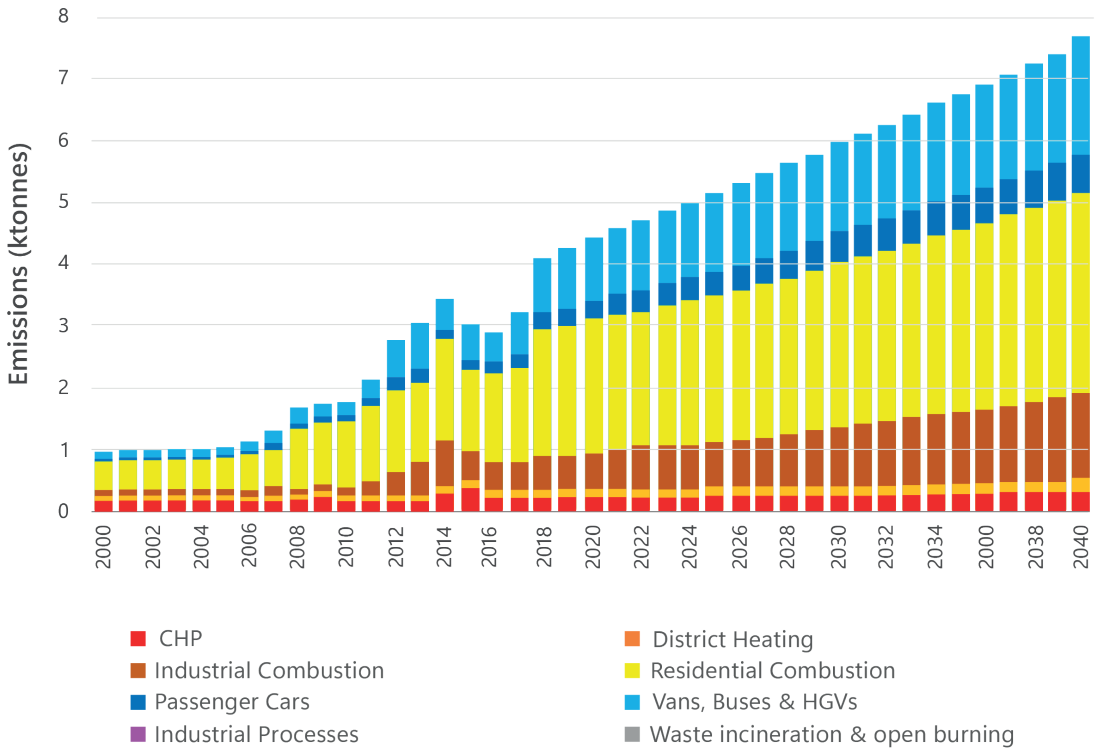


Figure 46 $PM_{2.5}$ emissions (With Measures scenario).

8.4.4 Sulphur Oxides (SO_x as SO_2)

SO_2 emissions are dominated by the sulphur in coal being released into the air when it is burned. As a result, it is the largest coal consumers which are the largest sources (**Figure 47**). Large point sources are often equipped with emissions control equipment that can be 99 per cent efficient at removing SO_2 from emissions. It is known that CHP is equipped with control equipment, but it is not currently clear how efficiently it is operating, and therefore the potential to improve the current levels of SO_2 removal by improving the emissions control.

A significant reduction in SO_2 emissions would be achieved if CHP used gas rather than coal, but this is a complex issue that would need to include considerations about fuel security, the cost for conversion/modernisation, and the ultimate cost to the consumer per unit of electricity/heat produced.

The residential sector also makes a large contribution to the total SO_2 emissions, due to the amounts of coal used for heating. Domestic appliances do not have emissions control equipment installed. Changing to a more efficient modern appliance would mean less coal use and hence lower emissions, but the impact would be small compared to e.g. switching from coal to an alternative low sulphur fuel. The same principle applies to emissions from industrial combustion.

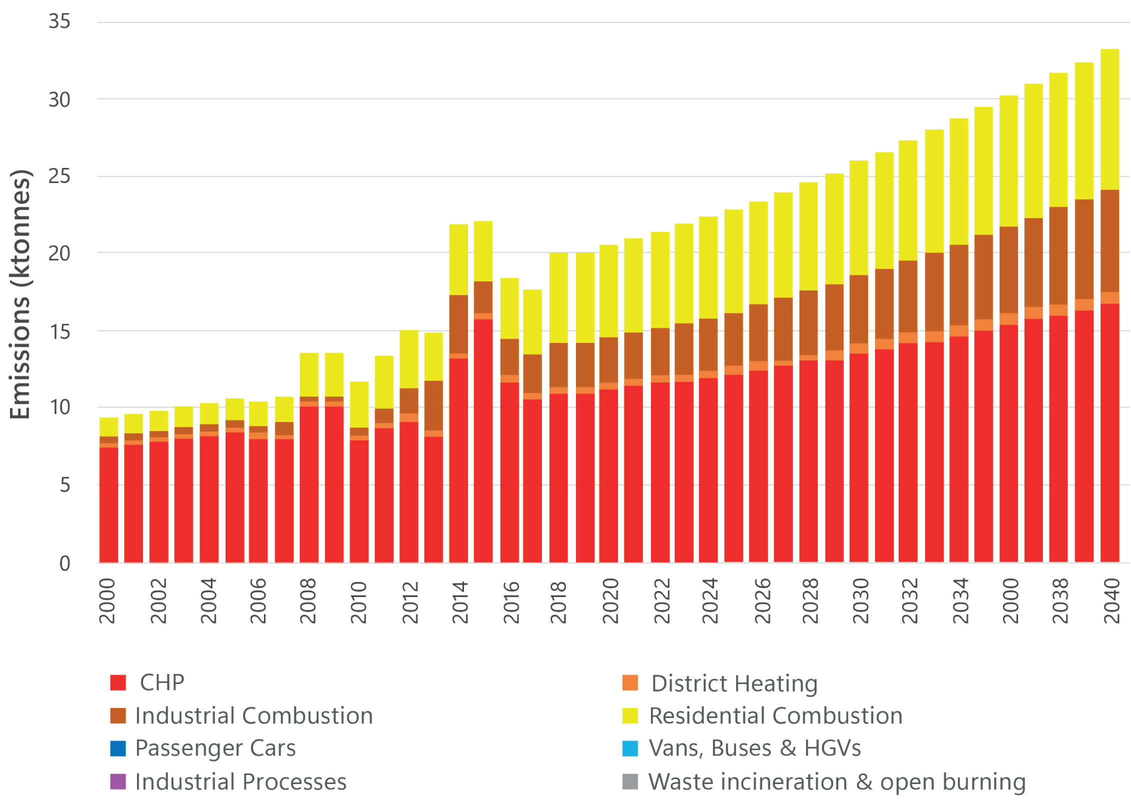


Figure 47 SO_2 emissions (With Measures scenario).

8.4.5 Non-Methane Volatile Organic Compounds (NMVOC)

Emissions of NMVOC are dominated by passenger cars, and hence emissions in future years are very much dependent on the vehicle fleet and the total number of kms driven (or fuel used) (**Figure 48**).

Introduction of the three-way catalyst resulted in large decreases in emissions from cars. The emissions reductions per km vary depending on how modern the emissions control technology is, but even the use of emissions control equipment that was introduced several years ago reduces emissions by nearly a factor of 50. As a result, modernisation of the car fleet is expected to be one of the priorities in controlling NMVOC emissions, and large emission reductions can be achieved without a large uptake of electric vehicles.

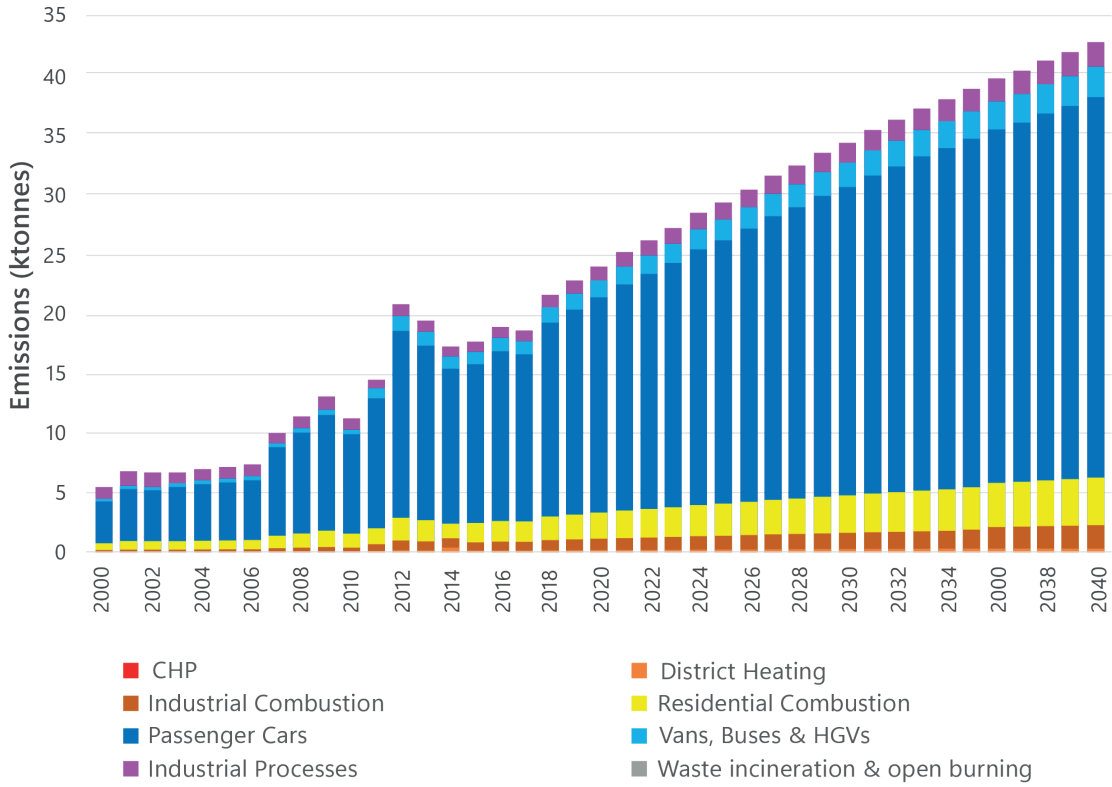


Figure 48 NMVOC emissions (With Measures scenario).

8.4.6 Other Pollutants

The inventory also includes emission estimates for a number of other pollutants, including: PM_{10}, mercury, dioxins/furans, benzo[a]pyrene, and CO_2. These pollutants are not reported here in detail because they are typically of less concern when considering impacts on human health in urban locations (although they may be important under specific circumstances, e.g. in close proximity to large industrial installations) In summary:

- **PM_{10} –** The relative contributions from different sources and the trends with time are very similar to those for $PM_{2.5}$.
- **Mercury –** Emissions of mercury are dominated by the use of coal, and so the relative contributions to the total emission, and the trends with time are very similar to those for SO_2.

- **Dioxins/furans –** Emissions primarily arise from inefficient burning of fuels. Residential use of coal is by far the largest source, accounting for nearly 80 per cent of the total emission in 2018. A change from a conventional stove to a modern appliance is expected to approximately halve the emission. Industrial combustion accounts for most of the remaining emissions.

- **Benzo[a]pyrene –** Benzo[a]pyrene is used as an indicator for polycyclic aromatic hydrocarbons (PAHs). The emissions profile and trends are very similar to those for dioxins/furans.

- **CO_2 –** Whilst not an air pollutant, CO_2 is the most important greenhouse gas, and it has been straightforward to include emission estimates whilst compiling the emissions inventory. In 2018, road transport was the largest source, accounting for nearly half of the total emissions. CHP was also a major source, accounting for over a third of the total emissions. Reducing CO_2 emissions requires less use of fossil fuels. This usually aligns with policies and measures targeted at reducing air pollutant emissions, although for air pollutants the use of emissions control equipment is usually effective.

There are other air pollutants which are reported to the CLRTAP were not considered to be a priority and were therefore not included in the emissions inventory. A full list of pollutants reported by Parties to the CLRTAP is included in Appendix 1 for information.

8.4.7 Improving the Emissions Inventory

Whilst the results from the emissions inventory are presented here, it is recommended that inventory improvements are undertaken before any substantial investment is made in policies and measures that are based on the emission estimates and emissions projections.

Suggested improvements to the emission estimates and projections have been discussed with local counterparts and experts. A list of key datasets has been compiled that would provide significant improvement to the current estimates, and work is underway to investigate whether it is possible to obtain the various datasets from government departments or other relevant organisations. In some cases it may be that the required data does not exist (rather than simply being unavailable), and new data collection would be required. This is typically time consuming and can be a significant undertaking.

Data that would help improve the emissions inventory is summarised in **Table 11** below. Where data cannot be obtained, it will be necessary to improve on the assumptions currently included in the inventory by consultation with relevant local and regional experts. Additionally, data of disaggregated by sex on populations in certain areas would also be critical as this data can provide crucial patterns that might support the linkage to gender-differentiated health impacts and outcomes, and thus support the formulation of integrated policies that are more effective and sustainable.

Table 11. Data required to improve the emissions inventory.

Sector and Dataset	Priority
Public Electricity and Heat Production	
Time series of fuels used in CHP	H
Emissions control/abatement equipment in use in CHP and changes with time	H
Time series of fuel used in District Heating	M
Emissions control/abatement equipment in use in District Heating, and changes with time	M

Sector and Dataset	Priority
Industrial combustion	
Time series of fuel used in industrial combustion	M
Information on fuel use in large industrial point sources	L
Emissions control/abatement equipment in use for large industrial plant	M
Road transport	
Fuel use (or km) estimates for Bishkek, for each year, split by vehicle type	H
Information on the vehicle fleet – numbers by vehicle type (and age) for each year, including the extent to which catalytic converters are removed	H
Other transport and mobile machinery	
Aviation - Annual flights arriving/landing at the airport (inclusion/exclusion in the inventory to be confirmed)	L
Rail - Diesel use (arrivals/departures at Bishkek stations) for freight and passenger trains	L
Mobile machinery – fuel use/hours of operation estimates	M
Residential combustion	
Fuel use in the residential sector, broken down into different fuels and different city areas	H
Home boiler/heating appliance types and technologies, broken down by city area	H
Fugitive emissions, industrial processes and product use	
Volume of fuel throughout at oil refineries	M
Kms of gas pipelines (split by type)	L
Fuel sales at petrol stations	L
Information on emission controls at petrol stations (tanker deliveries, storage, car refuelling etc.)	L
Solvent use in industry	L
Domestic use of paint, cosmetics and pharmaceuticals	L
Waste management	
Landfill – quantified information on the landfill fire	H
Water & sewage treatment – throughput at treatment works and other management systems	L

Legend

Very important to obtain/estimate	High
Important to obtain/estimate	Medium
Less important to obtain/estimate	Low

9 EMISSION PROJECTION SCENARIOS

The emissions inventory has been compiled not just to quantify historical emission estimates, but also to investigate future emissions under different scenarios.
To support policy development, it is necessary to have:

- A high-quality historical inventory, on which projections can be based. Accuracy and completeness are particularly important quality metrics.

- Accurate projections of current trends to give a business-as-usual scenario, more accurately referred to as a "With Measures" (WM), that assumes current and planned policies and measures are implemented. Projections that are calculated by scaling emissions sources by either population or GDP forecasts will not represent future trends accurately.

- An emissions inventory data structure that is sufficiently detailed, and detailed input data. This is so that policies and measures (which may change emissions in a highly selective way) can be suitably represented in the emission projection calculations.

- Collection of data disaggregated by sex on affected populations to better address trends and support integrated policy formulation approaches.

Three scenarios were developed that outline how the emissions from different sources might be controlled using different levels of ambition. To use the scenario information in the emission projection calculations, it was necessary to convert the descriptions of trends and policies into changes that matched the sources in the inventory using the following approach:

- **Estimates of how much of a source sector would be affected –** it is not necessarily the case that all of a source is affected. For example, modern heating appliances might be installed in 30 per cent of households using simple stoves, or a phased approach might be used across several years to install modern heating appliances in all households. In some cases it can be challenging to estimate the penetration of a policy. For example, rather than indicating that 30 per cent of households change from simple stoves to modern heating appliances, a policy might be to discount new appliances. In which case it is necessary to evaluate the relationship between the price discount and the take-up, and this is often not supported by locally sourced data or studies, and therefore requires expert judgment.

- **The extent to which the emissions are affected –** some policies/measures might result in a small reduction in emissions, and others in a large reduction. The difference can depend on subtle details in the policy and the way it is implemented, but quantification of the impact of the policy is usually determined by changing the emission factors. There are also examples where emissions reductions in one source sector requires emissions in another sector to be increased. For example, converting coal-based residential heating to electricity reduces the residential emissions by 100 per cent, but increases emissions from the electricity generating sector.

9.1 An Overview of Emission Scenarios

Three scenarios of different ambition levels were outlined for emission projections to 2040 (**Table 12**):

- **With Additional Measures Scenario 1, moderate ambition:** The economy, national energy mix, and Bishkek city fuel mix continue on the current trajectory, with investments in renewable energies and energy efficiency limited largely to development projects, implementing pilot projects with little overall impact on national emissions reduction, and little investment from the national government around scaling up and replicating demonstration projects. Electricity and energy tariffs remain low, energy governance issues exist, and consequently there is a lack of international investment in the national energy system. Issues hampering development of large-scale hydropower are ongoing, while development projects support sporadic development of some mini and micro hydropower stations. Meanwhile, climate impacts, including increased water stress continue, placing further pressure on existing water resources and, in turn, the generation of hydroelectricity, incentivising use of coal and other fuels particularly for wintertime heating when energy demands are highest. Climate targets outlined in the country's 1st NDC (submitted 2021) are not met.

- **With Additional Measures Scenario 2, higher ambition:** With political commitment, Kyrgyzstan develops ambitious plans to attract international investment to support reforms in the energy sector to address the energy crisis and reap their air quality co-benefits. As a developing country, Kyrgyzstan argues for a transition via lower emitting fossil fuels (gas) rather than a direct transition to renewables. Support is gained from development and other partners to make this transition in line with the country's NDC, freeing up climate finance and supporting completion of long-expected hydro and other projects. Developments are made in line with sustainable development principles, and plans are effectively and transparently implemented. While the economic crisis deepens, reforms in the energy sector are seen as a way to partially address this through new opportunities in developing a transparent renewables sector. However, social inequalities remain, and poorer households and marginalised groups have greater difficulty participating in and accessing the benefits of the transition.

- **Net Zero 2050 Scenario, very high ambition:** With strong political will and wide-ranging political and financial support from development and other partners, Kyrgyzstan actively and rapidly embarks on a pathway to transition to net zero emissions by mid-century. This involves widespread reforms in the energy sector, radical economic reforms, and meaningful reports to achieve transparent energy governance. Kyrgyzstan utilises its existing domestic resources, developing its significant renewable energy potential. This is also a just transition, actively including and supporting women and marginalised groups to participate in and benefit from the energy transition.

The table below provides an overview of how these scenarios were interpreted in terms of the extent to which different policies and measures are assumed to be applied, and what this means for datasets used in the emissions inventory.

Table 12: Emission scenarios: An overview of the policies and measures included.

Sector	Description of change		
	With Additional Measures Scenario 1	**With Additional Measures Scenario 2**	**Net Zero 2050 Scenario**
CHP & District Heating	• CHP is transitioned to gas during the wintertime (October - March) and improves emissions control efficiencies. • Some of the district heating large and small heat only boilers (40 per cent) transition from coal and oil to gas.	• CHP is fully transitioned to gas and improves emissions control efficiencies. • Some of the district heating large and small heat only boilers (60 per cent) transition from coal and oil to gas.	• CHP is phased out and closed by 2040 as electricity from renewables increase. • Fuel use in district heating reduces by 90 per cent, being substituted by renewables.
Industry	• There is some fuel switching from coal to gas (30 per cent by 2040).	• There is some fuel switching from coal to gas (30 per cent by 2040).	• There is some fuel switching from coal to gas (60 per cent by 2040).
Residential Sector	• Growing population and internal migration to Bishkek leads to growth in city population and growth of 'new settlements' around Bishkek. • For those living in private houses, there is some fuel switching from coal to gas for both residential stoves and boilers (25 per cent by 2040). Gas continues to be used for wintertime heating in middle-class neighbourhoods not supplied by CHP. • There is limited implementation (30 per cent) of improved insulation/energy efficiency in residential buildings with coal-based heating.	• Growing population and internal migration to Bishkek leads to growth in city population and growth of 'new settlements' around Bishkek. • For those living in private houses, there is some fuel switching from coal to gas for both residential stoves and boilers (35 per cent by 2040). Gas continues to be used for wintertime heating in middle-class neighbourhoods not supplied by CHP. 25 per cent of houses have heating systems based on renewables installed by 2040. • Half of residential houses/buildings with coal-based heating have improved insulation/energy efficiency installed.	• Growing population and internal migration to Bishkek leads to growth in city population and growth of 'new settlements' around Bishkek. • 80 per cent of heating and electricity is provided by renewable sources, the remainder by modern gas appliances. • Half of residential houses/buildings with coal-based heating have improved insulation/energy efficiency installed.

Sector	Description of change		
	With Additional Measures Scenario 1	**With Additional Measures Scenario 2**	**Net Zero 2050 Scenario**
Road Transport	• There is no significant modal shift from cars to public transport or walking/cycling. There is no significant uptake of private electric cars or fuel switching to gas (LPG/CNG). • The car fleet does significantly modernise through natural turnover, and vehicles are checked to stop catalytic convertors/emissions control equipment being removed. As a result, half of the cars and minibuses (petrol and diesel) are equipped with catalytic convertors/emissions control by 2040. • By 2040, all lorries and buses are using modern emissions control equipment.	• Private electric cars grow to be 15 per cent of the car fleet by 2040. • The car fleet does significantly modernise through turnover, which is enhanced by a scrappage scheme and vehicles are checked to stop catalytic convertors/emissions control equipment being removed. As a result, approximately 75 per cent of the cars and almost all minibuses are equipped with catalytic convertors/emissions control by 2040. • By 2036, all lorries and buses are using modern emissions control equipment.	• Private electric cars grow to be 70 per cent of the car fleet by 2040. • All remaining petrol/diesel cars and minibuses are equipped with catalytic convertors/emissions control. • By 2036, all lorries are using modern emissions control equipment, and buses are all either electric or are using modern emissions control equipment.
Waste	• Emissions from the landfill site are outside the scope of the emissions inventory, so policies and measures have not been considered (the impact of the landfill fire on air pollutant concentrations in Bishkek requires further investigation).		

These emission scenarios have been designed to reduce the future emissions of NO_X and $PM_{2.5}$. Projections of other pollutants have been included in the analysis, but only NO_X and $PM_{2.5}$ are shown below.

9.2 NO_x Emissions under Different Scenarios

The following plots present the emissions of NO_x under the three different scenarios.

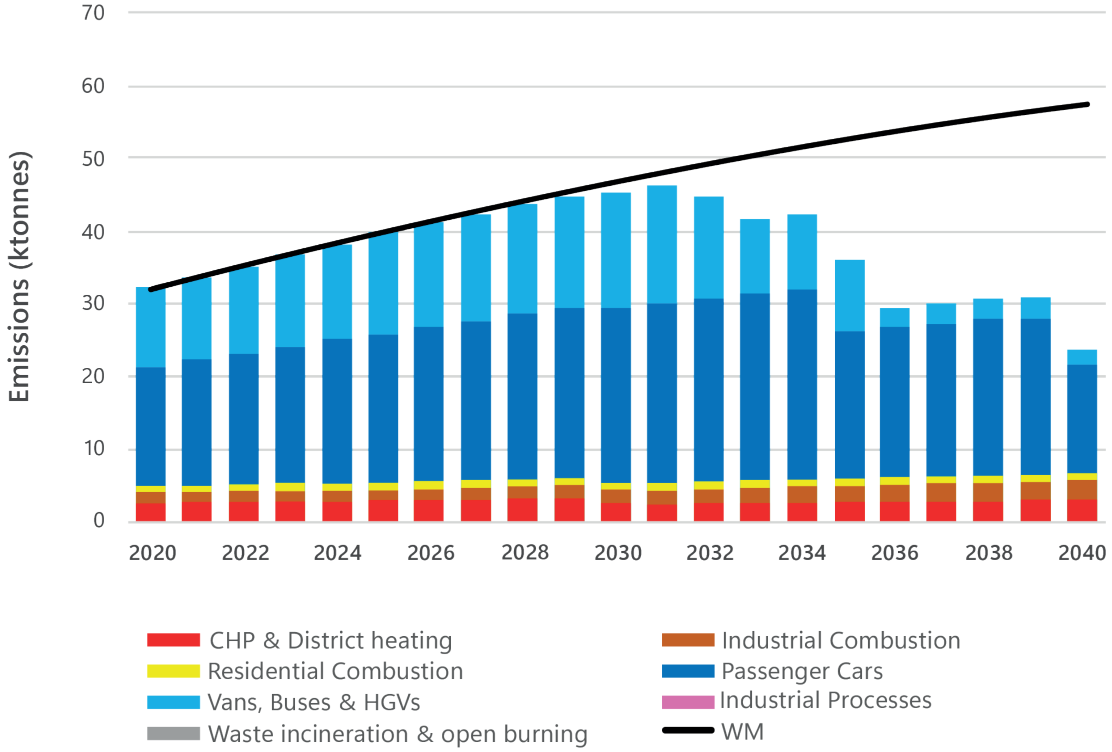


Figure 49 NO_x emission projections under the WAM1 Scenario (With Measures ("WM") emissions are included for reference).

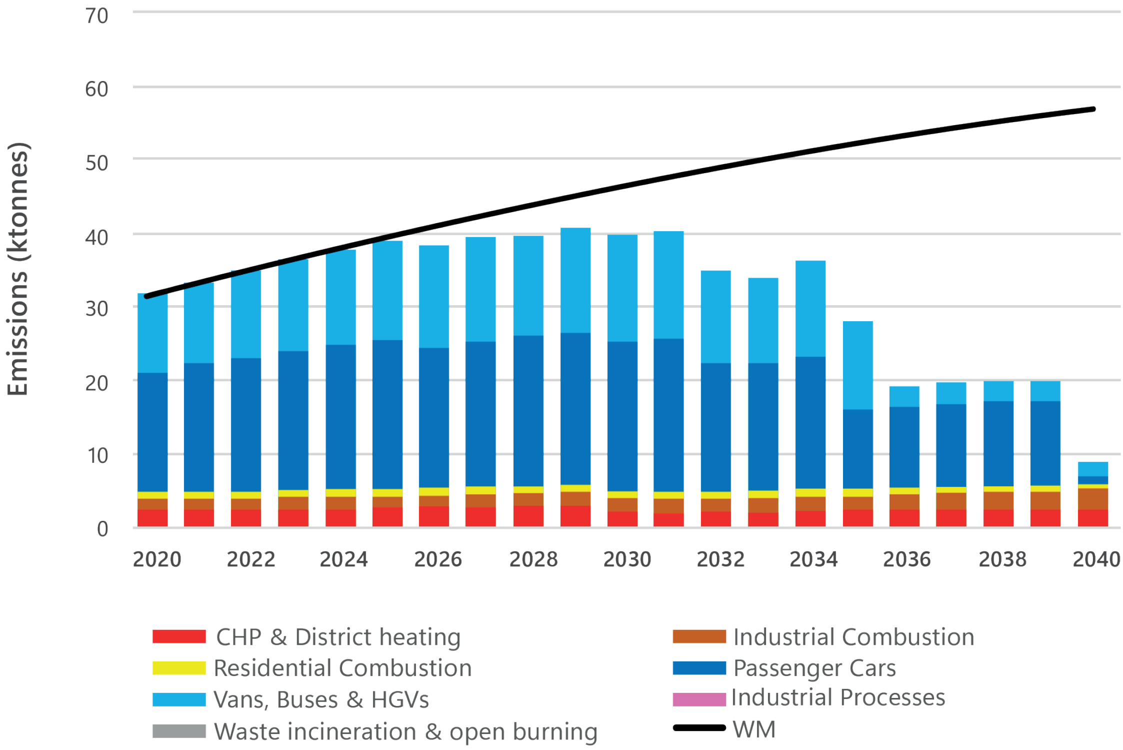


Figure 50 NO_x emission projections under the WAM2 Scenario (WM emissions are included for reference).

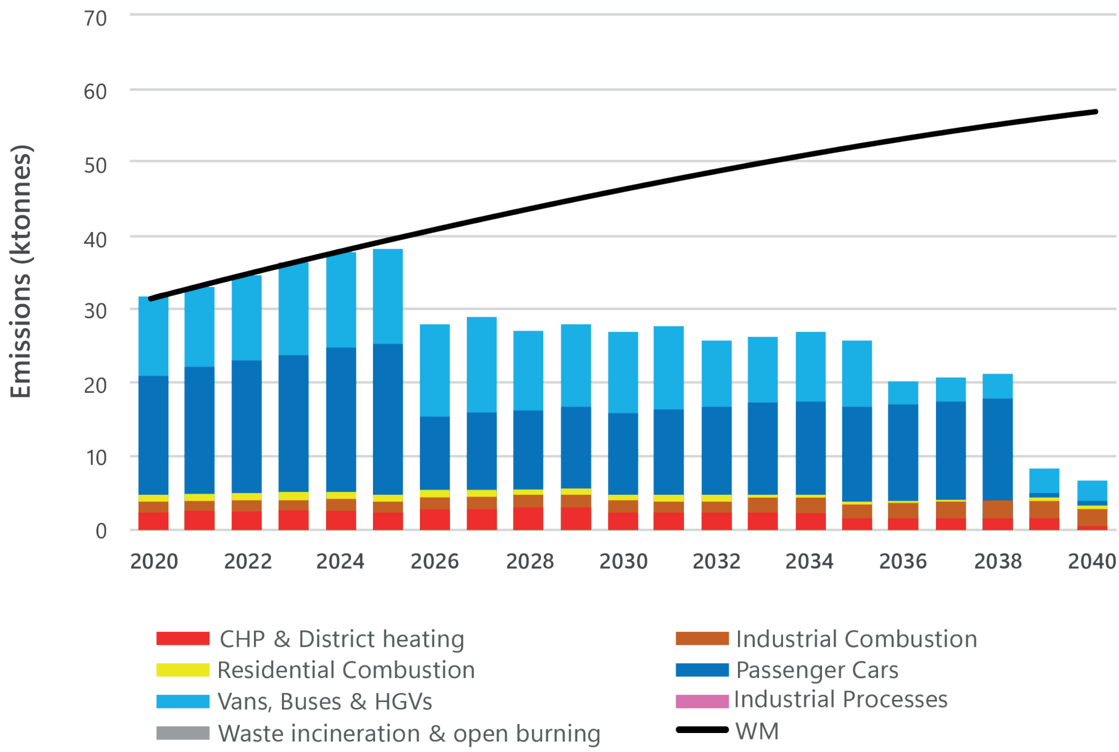


Figure 51 NO_x emission projections under the NZ2050 Scenario (WM emissions are included for reference).

As emissions from road vehicles make the largest contributions to the NO_x emission total, it is these policies and measures which are most important in controlling emissions. Under the WAM1 scenario, a reduction on the 2020 emissions can be achieved by 2040 through the introduction of petrol cars that are equipped with catalytic convertors and diesel cars that are equipped with diesel particulate filters. But the large emission reductions achieved in the WAM2 scenario are due to the greater penetration of these types of vehicles into the car fleet by 2040. The impact is to remove road transport emissions from being the largest source sector. This is shown as a step-change reduction for 2040 in **Figure 51** but would more likely be achieved as steadily decreasing emissions across several preceding years.

9.3 $PM_{2.5}$ Emissions under Different Scenarios

The following plots present the emissions of $PM_{2.5}$ under the three different scenarios.

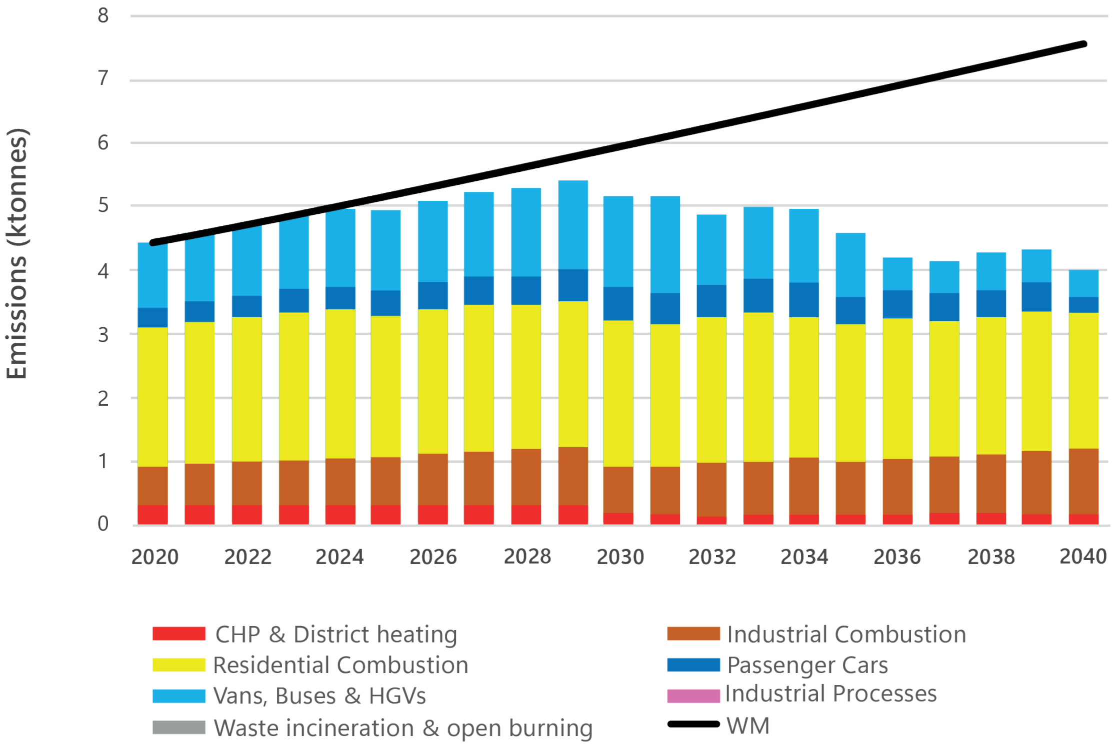


Figure 52 $PM_{2.5}$ emission projections under the WAM1 Scenario (WM emissions are included for reference).

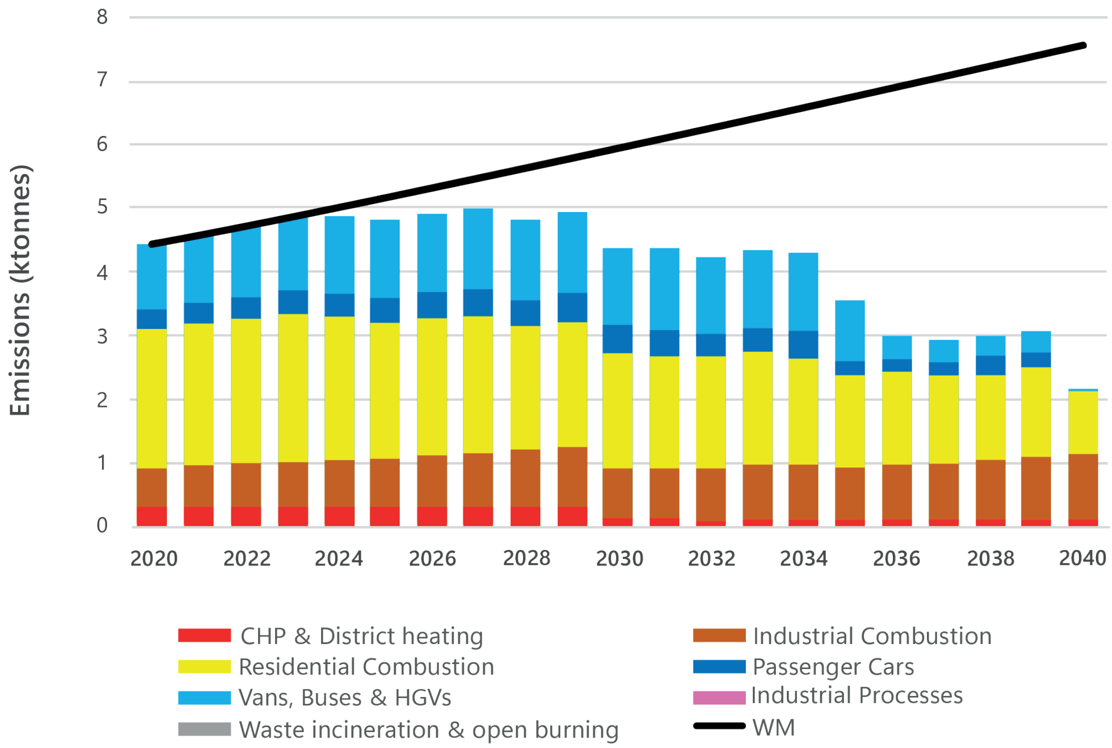


Figure 53 $PM_{2.5}$ emission projections under the WAM2 Scenario (WM emissions are included for reference).

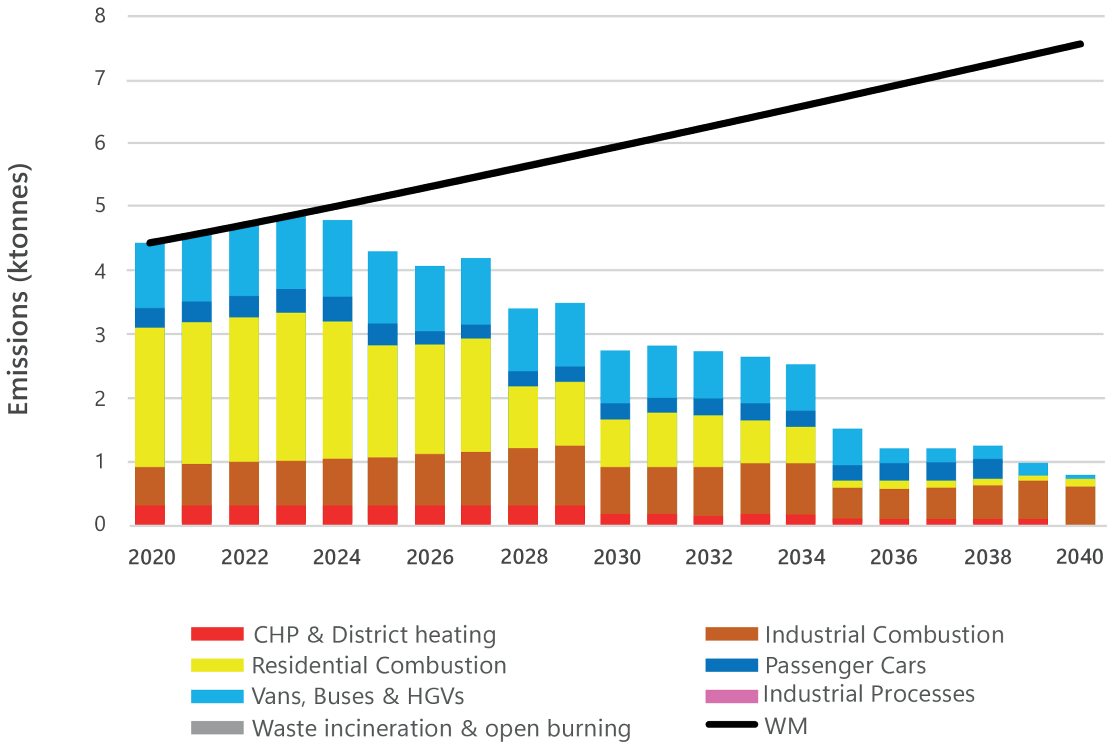


Figure 54 $PM_{2.5}$ emission projections under the NZ2050 Scenario (WM emissions are included for reference).

Residential coal use is the largest source, but the policies included in WAM1 only give rise to relatively small reductions that counter the growth (which is driven by a growing population). This shows that if the policies included in the WAM1 scenario (use of modern heating appliances and home insulation) are used, then a much greater level of penetration is needed. The NZ2050 scenario shows a much more successful reduction of residential emissions because households change from coal to electric heating, effectively reducing heating emissions from these houses to zero. There is no increase in emissions from electricity generation because it is assumed in the scenario that electricity is generated by renewables, rather than fossil fuel consumption.

The data that underpins the analysis shown in the figures above is high in uncertainty. But the results provide a guide to the ambition level that is required to make significant reductions to emissions of NO_X and $PM_{2.5}$. The data suggests that by 2040, the emissions of both NO_X and $PM_{2.5}$ could be half that of 2020 emissions if the right policies and measures are introduced, primarily to control emissions from road transport and the residential sector.

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