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.