HEALTH AND SOCIAL IMPACTS OF AIR POLLUTION ON WOMEN AND CHILDREN IN BISHKEK, KYRGYZSTAN

ENTRY-POINTS FOR ACTION

IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

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Health impact estimates are not intended to be predictors of disease in individuals; rather they are intended as an objective assessment of health impacts on a population basis. These assessments do not take the place of the detailed economic evaluations required to identify national energy priorities, national and global work on mapping disease incidence nor the social and political considerations required in implementing major social interventions in public health. However, the process of data collection and analysis is aligned with UNICEF's strategic guidance note on ethical practice for research.

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ACRONYMS

ALRI	Acute lower respiratory infection
COPD	Chronic obstructive pulmonary disease
DALY	Disability-adjusted life year
DHS	Demographic and Health Surveys
GDP	Gross domestic product
HEPA	High-efficiency particulate air filter
IHD	Ischemic heart disease
MICS	Multiple Indicator Cluster Surveys
NO_2	Nitrogen dioxide
O_3	Tropospheric ozone
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 μm at the 50th percentile cut-off
PAH	Polycyclic aromatic hydrocarbons
SO_2	Sulfur dioxide
VOC	Volatile organic compounds
WASH	Water, sanitation and hygiene
WHO	World Health Organization
IHME	Institute of Health Metrics and Evaluation

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

EXECUTIVE SUMMARY

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All countries in which households use solid fuels in urban areas for winter space heating have an air pollution problem that contributes significantly to burdens of disease. Kyrgyzstan is no exception. The Kyrgyz Republic National Development Strategy 2018-2040 sets forth three main goals, namely: (i) economic well-being of the people; (ii) social welfare; and (iii) security and favorable environment for the lives of citizens. Law No. 51 on "protection of atmospheric air" states that citizens have the right to atmospheric air favorable for life and health, to receive reliable and timely information about the state of atmospheric air and measures taken to protect it, including compensation for damage in case of damage to their health and property caused by emissions of pollutants.

With increasing concerns over high wintertime fine particle ($PM_{2.5}$) air pollution concentrations experienced in Bishkek that are far in excess of those known to have major adverse health effects in urban populations, UNICEF initiated this study in partnership with M-Vector. The purpose of the analysis is to examine the health and social impacts of $PM_{2.5}$ air pollution on children and women in Bishkek and develop recommendations on appropriate disease prevention measures based on the most up-to-date assessment of the theme. The technical roundtable was organized in Bishkek on 4 November 2022, where experts, government officials from line ministries and technical stakeholders were invited to review the draft for comments and suggestions.

To respond to some of the gaps in the evidence base, primary data were collected on spatial variability in $PM_{2.5}$ air pollution concentrations in the urban area, prevalence of primary and additional household space heating fuels, impacts of heating types on infiltration of outdoor pollution into indoor environments, knowledge of clean and sustainable options and willingness to pay for an increase in years of healthy life without illness due to air pollution. Health impacts were assessed using baseline health incidence data reported by Kyrgyz Republic combined with integrated exposure response curves for $PM_{2.5}$ used in Global Burden of Disease estimates1 which relate exposure to $PM_{2.5}$ with the population attributable fraction of disease risk. The assessment had the following key activities: 1. Rapid situational analysis; 2. Validated low-cost sensor measurements of indoor and outdoor household air pollution; 3. Urban scale air quality assessment of outdoor $PM_{2.5}$ gradients within Bishkek; 4. Exposure and health impact assessment; 5. Household survey with contingent valuation subsample; 6. Economic analysis of impacts of air pollution; and 7. Recommendations on appropriate disease prevention measures.

Key Findings

The current analysis shows that the right to atmospheric air favorable for life and health is far from the current reality for residents of Bishkek. Between 7/1/2021 and 6/30/2022, spatially weighted average annual ambient $PM_{2.5}$ concentrations in Bishkek were 44 $\mu g/m^{-3}$, a level far in excess of those known to have major adverse health effects in urban populations. Figure 1 shows the spatial distribution of annual average ambient $PM_{2.5}$ concentrations in Bishkek for the ADB/Kyrgyzhydromet Clarity sensor network, bias adjusted. Annual average $PM_{2.5}$ concentrations vary by a factor of four across the Bishkek network (17-75 $\mu g/m^3$), with concentrations lowest in the south and central business districts consistent with prevailing southerly winds during the winter, intermediate in the east and west districts, and highest in the north. Across the city of Bishkek, therefore, residents are exposed to annual average concentrations that range from moderately elevated to far in excess of concentrations known to cause major health impacts in populations as a result of the prevalence of residential winter heating types in different spatial locations in the city.

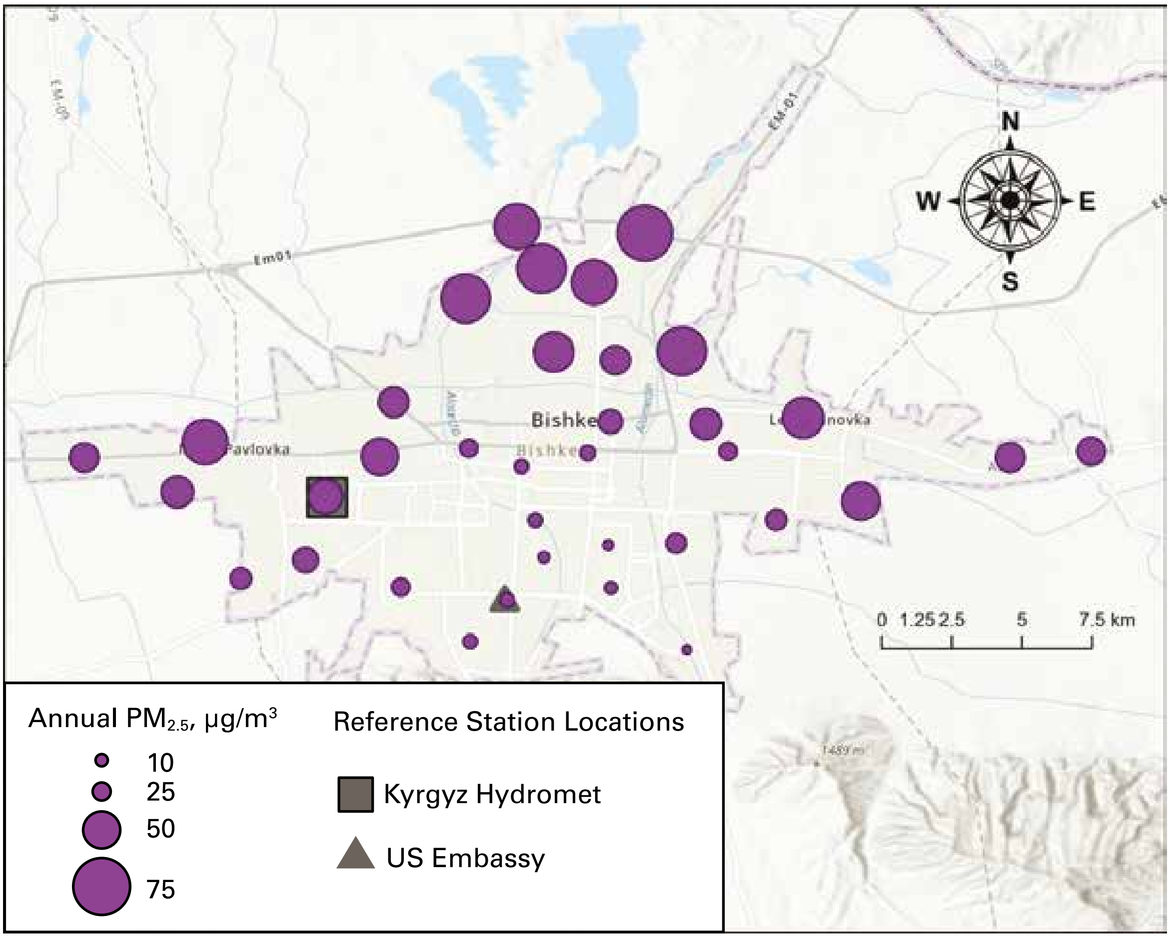


Figure 1. Annual average $PM_{2.5}$ concentrations (July 2021-June 2022) for the ADB/ Kyrgyzhydromet Clarity sensor network, bias adjusted.

Figure 2 shows spatial interpolation of wintertime concentrations of the ADB/Kyrgyzhydromet sensor network to obtain the $PM_{2.5}$ concentration surface for the city of Bishkek. Superimposed on this map are columns that represent the fraction of houses in the household survey enumeration area using coal stoves. This map visually demonstrates the relationship between higher $PM_{2.5}$ concentrations and the neighborhood use of raw coal stoves for space heating. The spatially weighted annual average concentrations were a factor 1.75 times higher than averages reported for the US Embassy monitoring site for the same time period due to location of the US Embassy monitoring site in the southern area of the city which has lower ambient concentrations of $PM_{2.5}$. While representing the urban area is not the primary purpose of the US Embassy monitoring site, the difference between the averages highlights the importance of site location of fixed monitoring sites and sensor arrays in spatially representing the urban area as the Government of Kyrgyzstan expands its monitoring capacities.

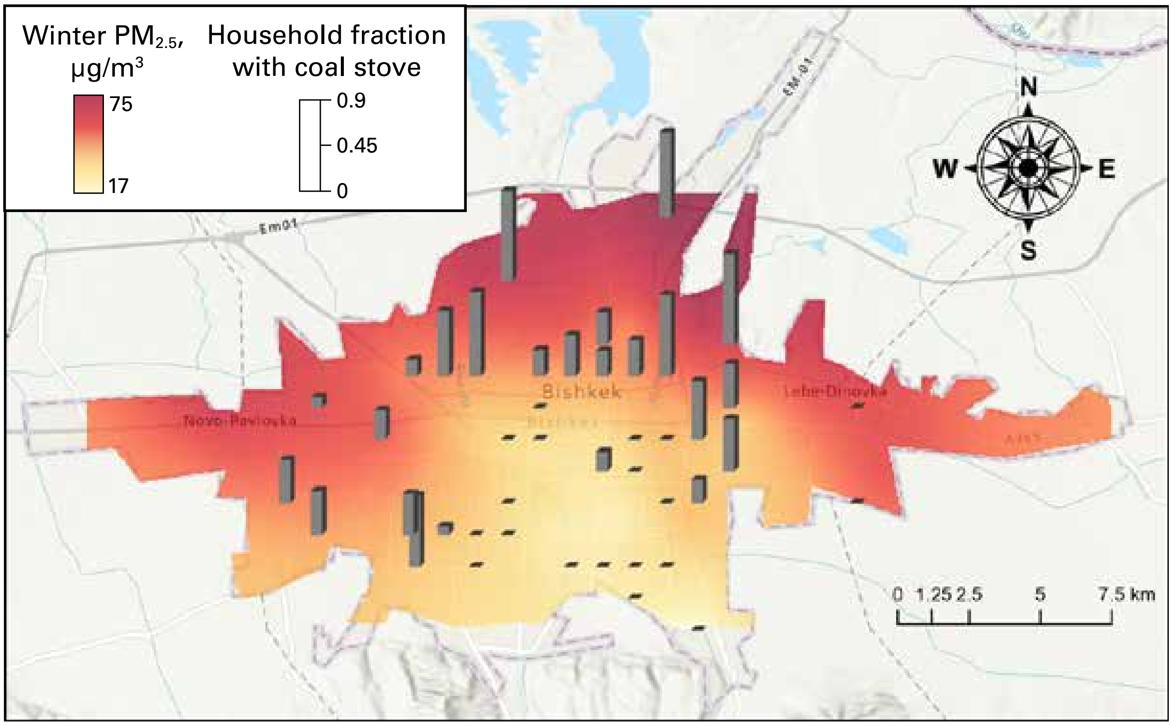


Figure 2. Spatial interpolation of wintertime concentrations in Bishkek city

Figure 2. Contours: winter average $PM_{2.5}$ concentrations (November 2021-January 2022) for the ADB/Kyrgyzhydromet Clarity sensor network, bias adjusted. Columns: Fraction of households using raw coal stoves from the household survey. The two zones to the east with no stoves are apartment areas adjacent to neighborhoods with detached homes using raw coal stoves.

Primary space heating in Bishkek reported in the household survey was approximately 48% central heating, 26% raw coal stoves, 17% gas, 8% electric (Figure 3). Burning raw coal for space heating decreased up income strata from 40% in the lowest income strata to 17% in the highest income strata, however continued prevalence of coal stoves in upper income strata represents a clear target for clean and sustainable alternatives, given that initial purchase price and affordability are lower constraints in these groups. Since MICS 2018 use of gas as primary fuel for space heating increased by over 12% and use of raw coal in stoves decreased by 14%, which represents a move in the right direction, although much still remains to be done. Approximately 23% of homes reported using additional fuel types for space heating with wood accounting for 60% of additional fuel used in stoves, which highlights the need for additional survey questions on space heating fuel use in MICS surveys. The household surveys also demonstrated lack of awareness of the use of clean and sustainable heating options (Figure 4) and the relative costs compared to burning raw coal.

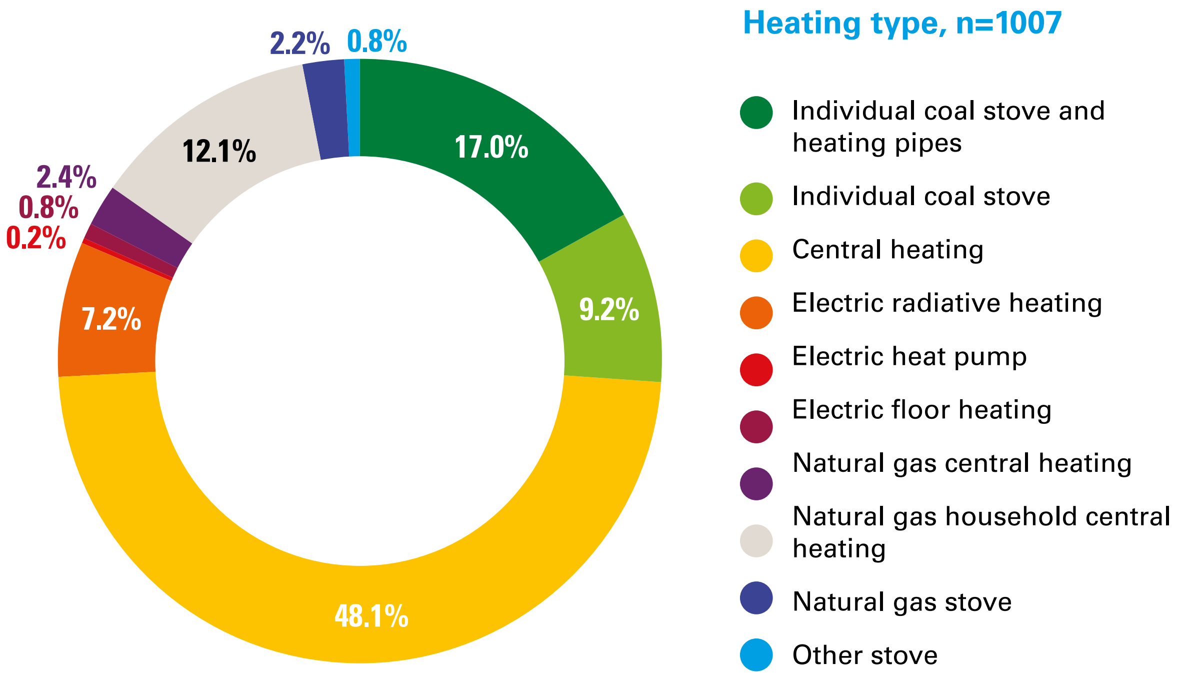


Figure 3. Primary source of winter space heating.

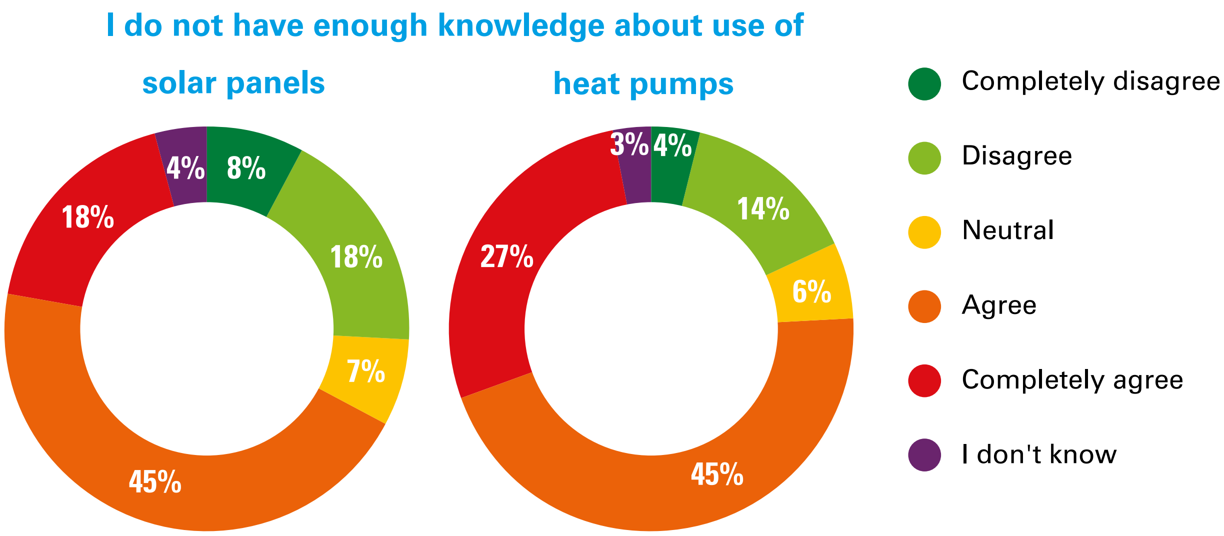


Figure 4. Perceptions of household residents about use of solar panels and heat pumps.

Based on time activity data collected by the Government of Kyrgyzstan and indoor-outdoor monitoring of households with different heating types, population weighted annual average exposures for the household survey representative sample were estimated to be 18.0 µg/m^{-3}, with annual average population weighted exposures for children under 10 years old 18.5 µg/m^{-3}, and for adults 17.7 µg/m^{-3}. Figure 5 shows that average household exposures during winter reflect the prevalence of neighborhood residential winter heating types. Children and youths living in homes that burn raw coal for space heating are more exposed by on average 33% (7.5 μg/m^{-3}) during the year and 37% (17 μg/m^{-3}) during the winter because of the neighborhood-scale pollution from raw coal stoves that infiltrates their homes, compared to children with central heating. Children that live in apartment buildings, however, are still exposed to urban level ambient air $PM_{2.5}$ concentrations that infiltrate into their indoor environments. Thus all children in Bishkek would benefit from measures to reduce air pollution emissions.

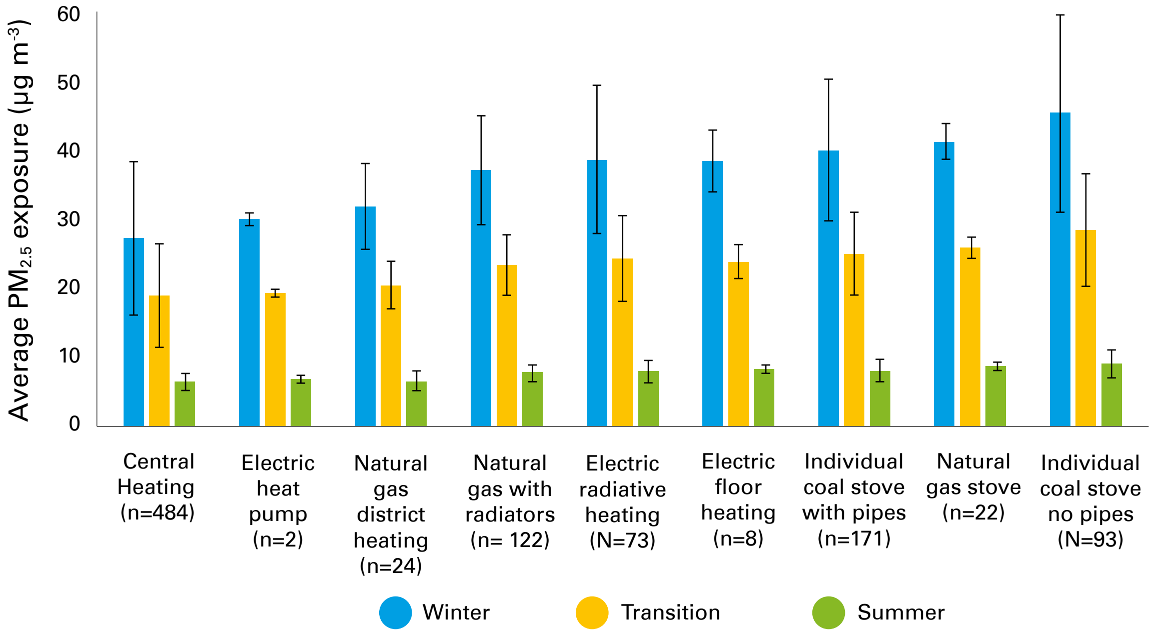


Figure 5. Average household $PM_{2.5}$ exposures by primary winter heating type. Winter = November-January; Summer = May-September; and Transition = February, March, and October.

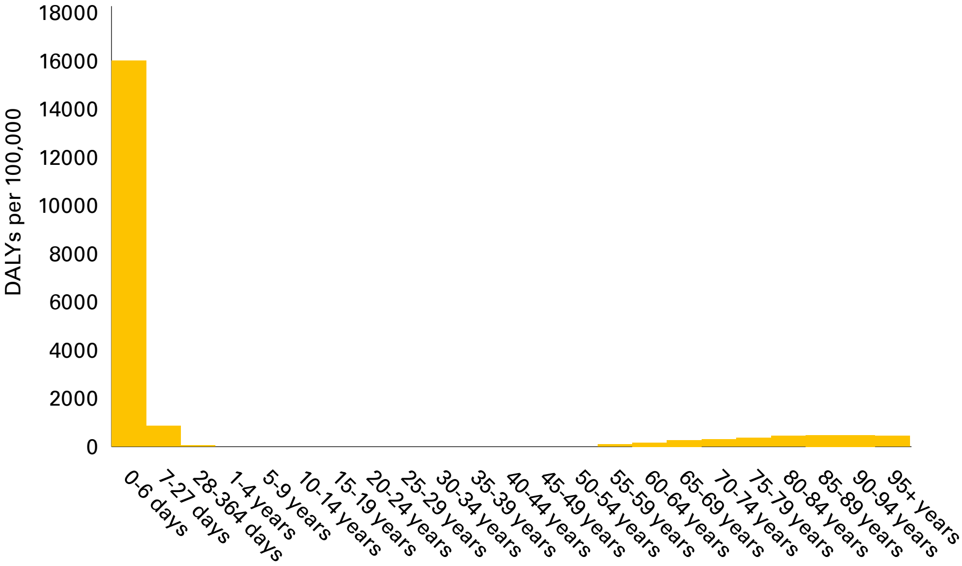
Annual average population weighted $PM_{2.5}$ exposures across all household types were on average ~3.6 times those known to cause adverse health impacts in populations, causing an estimated 112 Deaths and the loss of 3,568 Disability Adjusted Life Years (DALYs)[i] for this one-year time period. Children represented 22% of disease burdens attributable to $PM_{2.5}$ air pollution exposures in 2021 and efforts to reduce exposures during pregnancy and in the first year of life should be a high priority (see Section 3.6 for more details). Air pollution is the single biggest risk factor for premature death and ill-health in Kyrgyzstan.

Figure 6 shows $PM_{2.5}$ health impacts estimated for Bishkek weighted by IHME[ii] age specific disease burden for Kyrgyzstan, which shows the ill health due to $PM_{2.5}$ air pollution in Bishkek is primarily borne by the elderly and young children in the first days of life. The first chart (orange) is the rate of DALYs per 100,000, normalized by populations size in each age group, which shows that children in the days immediately after birth are most vulnerable to the impacts of air pollution and health effects are dominated by exposures to fine particulate matter (PM 2.5). The second chart (blue) shows that the absolute number of DALYs attributable to air pollution is high immediately after birth with the greatest impacts in the first 6 days, with a decline through childhood. Subsequently impacts of air pollution increase with age to peak

i Disability Adjusted Life Year (DALY) Mortality itself is not a good indicator for disease burdens, as all individuals will die at the end of their life span; rather it is the loss of years of healthy life due to premature mortality and the years of life spent with illness that represent the impacts of disease on populations. DALY is a metric that incorporates both the number of years of life lost due to premature mortality (YLLs) and years of healthy life lost due to disability (YLDs) to estimate the number of years of full health lost due to disease.

ii Institute for Health Metrics and Evaluation (IHME), 2022. Available from https://vizhub.healthdata.org/gbd-results/.

around 60 years old, and decline with lower population numbers at higher ages. Pollution is costly for individuals, families, and society with an estimated welfare loss to Bishkek of 1.6 billion KGS (95% CI 1.4-2.0) or 20 million USD (95% CI 17-24) in 2021-2022.



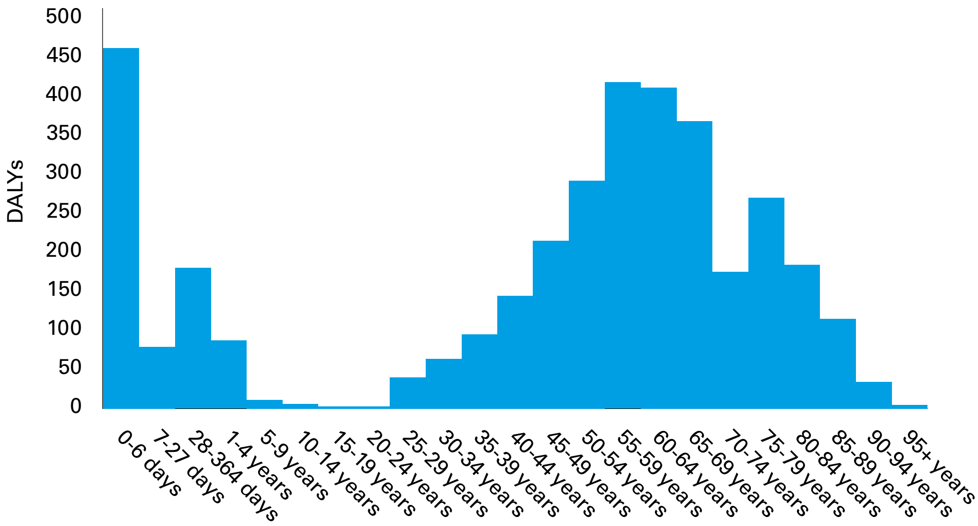


Figure 6. $PM_{2.5}$ health impacts estimated for Bishkek weighted by IHME age specific disease burden for Kyrgyzstan.

Table 1. Results at a glance
Health Impacts from $PM_{2.5}$ air pollution exposure were estimated to cause 112 (95% CI 97-131) Deaths and the loss of 3,568 (95% CI 2990-4220) Disability Adjusted Life Years (DALYs) between 7/1/2021 and 6/30/2022. Air pollution is the single biggest environmental risk factor for premature death and ill-health in Kyrgyzstan, with ill health due to $PM_{2.5}$ air pollution primarily borne by the elderly and young children in the first days of life.
Spatially weighted average annual $PM_{2.5}$ concentrations in Bishkek between 7/1/2021 and 6/30/2022 were 44 $\mu g/m^{-3}$, a level far in excess of those known to have major adverse health effects in urban populations. Annual average $PM_{2.5}$ concentrations vary by a factor of four across the city of Bishkek (17-75 g/m^3), with concentrations lowest in the south and central business districts and highest in the north.
Population weighted annual average exposures for the household survey representative sample were 18.0 $\mu g/m^{-3}$, with annual average population weighted exposures for children under 10 years old 18.5 $\mu g/m^{-3}$, and for adults 17.7 $\mu g/m^{-3}$. Exposures are driven by infiltration of local neighborhood $PM_{2.5}$ air pollution into indoor environments and are thus borne unequally by the population in Bishkek depending on the prevalence of stoves burning raw coal in different neighborhoods in the city during the winter. Annual average population weighted $PM_{2.5}$ exposures across all household types were on average ~3.6 times those known to cause adverse health impacts in populations.
Economic Impact: The estimated welfare loss from $PM_{2.5}$ air pollution in Bishkek was 1.6 billion KGS (95% CI 1.4-2.0) or 20 million USD (95% CI 17-24) in 2021-2022.
Availability and awareness of clean household alternatives and their relative costs is a key barrier to reducing air pollution (see survey results in full report for more detailed evaluation).
Capacity building is necessary to build institutional capabilities, technical resources, human resources, legal frameworks and informational resources.

Recommendations

The 2030 Agenda for Sustainable Development adopted at the United Nations Summit on Sustainable Development in September 2015 includes:

- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

Meeting these goals in Bishkek will require sustained and coordinated action to change the primary energy use for 26% of the urban population. With increasing awareness there are days that air pollution concentrations in Bishkek are reported to top the list of the world's most polluted cities, and growing interest of the multilateral and bilateral agencies to address the problem, *there is a need for coordination of actions through the EcoSovet inter-ministerial committee to ensure programmatic consistency and cost-effective use of time and resources. A long term strategic urban plan of what primary energy choices in Bishkek will look like over the next 10 years will aid in this endeavor.* The EcoSovet inter-ministerial committee should be well informed of the economic burdens of air pollution, and the health and economic benefits of investing in intervention strategies quickly rather than more gradually, as these play a significant role in the choice of strategic approach and the associated cost.

Although it is well established that improved population health outcomes are achieved most effectively by societal control of emissions, and that the health of all citizens will benefit from air pollution reductions, some of these transitions in other countries have been relatively rapid, while others have progressed more slowly due to political motivation and resources. In the meantime, however, it is important to recognize that there are strategies that can be implemented to reduce exposures and mitigate some of the health impacts in the current generation of children that are growing up in Bishkek. *Key measures to reduce impacts include targeting pregnancy and early days of life for exposure reduction strategies such as home air filtration units during pregnancy and the first 1000 days of life, ensuring young children can learn and play in low air pollution environments that limit lung damage and growth impairment, ensuring adequate nutrition during pregnancy and during the first 1000 days, and featuring locally grown antioxidant fruit and produce in school children's nutrition.* In addition, continued work to reduce prevalence of tobacco smoking in indoor environments will ensure health benefits from reducing other air pollution emissions are realized in the population.

As with many urban areas, air pollution causes and impacts are not contained within municipal boundaries as air pollution is transported downwind. *As a consequence, measures to reduce air pollution should extend beyond municipal boundaries to encompass the airshed, or the greater area causing and affected by urban $PM_{2.5}$ pollution, and the political and institutional mandates reflecting the larger urban airshed developed.* Examples of this approach include UK pollutant specific Air Quality Management Areas (AQMAs), which are defined based on the nature and spatial extent of the problem e.g. Birmingham, or the Air Quality Management Districts (AQMD) in the United States e.g. the south coast air quality management district that covers Los Angeles encompassing 17 million people in over 162 cities in 4 counties.

A designation of "no burn zones" for raw and phasing out of coal are key priorities for long term urban planning where clean alternatives are available to ensure ambient air pollution emissions are reduced within and upwind of current high concentration areas. However, no burn zones are dependent on the affordability, availability and acceptability of clean alternatives. To ensure a smooth transition, there is a critical need to model different price points in market based tiered pricing structures to avoid unintended incentives to return to solid fuel use by the most vulnerable as energy costs move toward cost recovery levels.

With many competing uses for limited resources, *there is a need to prioritize policies intended to reduce air pollution impacts identified in the action plan based on the cost effectiveness of the measure in reducing health impacts as the primary metric.* Current air pollution monitoring and e-health data do not yet provide an adequate evidence base for policymaking. *Improvements in the evidence base are needed both in the representativeness of environmental measurements, and also in e-health data collected in the city and surrounding areas including training of physicians in the public health objectives that can be evaluated through accuracy in International Classification of Disease (ICD10) coding.* The Government has started developing the capacity to monitor environmental impacts, including expansion of monitoring networks, and has initiated plans to improve e-health data. However, expansion of technical capacity and human resources more rapidly would be beneficial in improving epidemiological surveillance, and the ability to model potential impacts of policy interventions prior to implementation. *Accessibility and open sharing of data funded by taxpayers remain critical priorities in providing a transparent evidence base for policymaking.*

Increasing the energy efficiency of existing infrastructure through rehabilitation, moderating demand for energy and adopting clean and sustainable technologies play joint roles in reducing emissions. Technology solutions such as air-to-air heat pumps require piloting to demonstrate affordability and acceptability that can be used to educate the wider population. *Current survey results show lack of awareness in the populations of clean and sustainable household alternatives and their relative costs.* Energy efficiency measures including window, wall and roof insulation are needed to reduce energy demand in single homes, which allows clean technologies to be more affordable. *Purchase price incentives and finance options are a priority for newer technologies, and for energy efficiency improvements.* In central urban districts retrofitting of turndown ability and thermostats for buildings served by district central heating will allow available resources to supply more homes, whilst maintaining occupant comfort. While installed in new apartments, *technologies that allow retrofitting older apartments is a priority in order to expand the number of buildings district central heating can supply*.

Long term ambient air quality management relies upon identifying major emission sources and quantifying their contributions to the ambient air pollution burden, however *it is not necessary to wait for fine resolution on source contributions to know that residential burning of raw coal for space heating is the principal cause of the wintertime $PM_{2.5}$ air pollution problem in Bishkek, and that measures to reduce this pollution should be implemented immediately.* There are currently major limitations in applying conventional methods to quantify ambient $PM_{2.5}$ air pollution sector contributions. There is a lack of reliable emissions estimates and fuel consumption from households, facility level heat boilers, industrial emissions, small scale industries, roadside kiosks, and transportation fleets necessary for ambient air quality modeling using spatially and temporally resolved emissions estimates together with meteorology (bottom-up approach). *Modernization of emissions measurements and inventories is thus necessary before bottom-up air quality modeling will be useful for fine resolution on source contributions.* While emissions data is not necessary for source apportionment using a large dataset of collected $PM_{2.5}$ samples that have been analyzed for chemical composition (top-down approach) where chemical species are used to distinguish different sources, many sector contributions in Bishkek will not be resolved using this technique because these sectors use the same raw coal as fuel and covary with meteorology. While such approaches may be able to resolve some non-coal source contributions, these are currently small compared to sectors using raw coal.

Bishkek suffers from high levels of air pollution that vary widely across the city. *Improved awareness that household heating can be a significant contributor to poor air quality and lead to significant health burdens in the population will assist government and civil society in taking measures to reduce these sources. Similarly incorporating a health-based Air Quality Index (AQI) that is structured similarly across Central Asian nations would greatly assist in informing the government and population in real time about air pollution hazards and personal actions that can be taken to reduce exposures.* Large social transitions to reduce air pollution emissions require a well-developed communication strategy using modern communication techniques targeted at increased awareness in the population of the role played by burning raw coal in inefficient stoves and the urgency to address air pollution-related impacts. *Similarly, increasing the education about the health impacts of air pollution in schools and for professional groups such as teachers in training colleges and medical professions can play a significant role in delivering messages in hard-to-reach populations.* Increasing the availability of audio-visual materials on air pollution in school education programs, and promoting thematically-oriented art, essay and science fair competitions would significantly raise awareness of the hazards of air pollution among school-going children and provide information on feasible alternative measures that can be taken to reduce exposure.

Large numbers of vehicles using inefficient diesel engines not equipped with emission reduction technologies combined with ageing passenger and commercial vehicle fleets are prevalent in Bishkek. Once increased controls on household solid fuel sources, facility level boilers and industrial emissions are exercised, transportation emissions will play a greater relative role in urban ambient air pollutant concentrations. Without addressing transportation emissions, the 2030 Agenda for Sustainable Development Goals are unlikely to be met. Routine evaluation of vehicle emissions using dynamometers is not currently a feature of enforcement of vehicle emissions standards in Bishkek. Although initial attempts to implement monitoring using private laboratories were discontinued, *routine (e.g., annual) testing is critical in identifying significantly polluting vehicles with a mechanical malfunction in the vehicle fleet*. Experiences in other nations have shown that the 10 per cent of malfunctioning vehicles in the vehicle fleet contribute 90 per cent of the emissions, which can be controlled through vehicle emissions testing as part of routine vehicle inspection and enforcement.

Table 2. Opportunities to reduce $PM_{2.5}$ air pollution
Legislation, policy and planning
• Expand legal authority for control of air pollution beyond municipal boundaries through the creation of air quality management areas that encompass the settlements on the fringes of the city that predominantly use raw coal. • Increase the use of objective scientific information on the health and social impacts of air pollution in policy making. • Progressively target the major sources of air pollution guided by cost effectiveness of the intervention measures to improve health. • Centralize air pollution intervention measures under the EcoSovet inter-ministerial steering committee to coordinate actions across sectors, and formalize the strategic road map over the next 10 years of primary energy choices. • Prioritize the promotion of coal-free zones in urban areas to reduce household coal combustion, together with demonstration of cost-effective alternatives through incentive programs and financial models. • Increase the quality of e-health data and education of the health workforce on health impacts driven by air pollution.
Cost effectiveness and efficiency
• Pilot air pollution intervention measures to demonstrate effectiveness in reducing air pollution and affordability prior to expenditure of limited resources. • Use economic modelling of pricing structures to provide the incentive framework for wider adoption of clean alternatives. • Incorporate existing tools developed by multilateral organizations to allow policy makers to make informed policy decisions based on cost effectiveness of intervention measures. • Develop a communications strategy to inform residents of cost effectiveness of clean heating solutions.
Targeted measures
• Develop approaches to reduce exposures during pregnancy and in the first 1000 days of life, such as loans of air filtration equipment as part of prenatal and postnatal care. • Provide air pollution messages and education resources for incorporation into school curricula, and in teacher training colleges. • Increase the coverage of ambient air pollution surveillance.

- Increase incentives for energy conservation measures in all sectors, as it remains an important tool to reduce emissions from households, industries, facility level heat boilers, and allow expansion of district heating networks.
- Increase institutional capacity development opportunities for health care providers, education professionals and other stakeholders about the health impact of air pollution
- Energy Transitions: A key challenge to energy transition in Kyrgyzstan to clean household fuels is the cost and availability of clean alternatives. There is potential to address this through:
    - expansion of existing district central heating in central urban areas though energy efficiency measures, temperature regulation and turn down ability
    - expansion of gas distribution networks in residential urban areas
    - pricing incentives and finance mechanisms for connection to gas distribution
    - piloting air-to-air heat pumps together with the development of electricity pricing structures, pricing incentives and finance mechanisms to increase accessibility.
    - increase energy conservation measures in private residences
- Organizational frameworks:
    - modernization of ambient air quality and emission standards, combined with health based AQI
    - increasing air quality management technical capacity, human resources and enforcement abilities
    - better coordination and harmonization of plans and programs across stakeholders
- Integrate air pollution activities with WaSH, nutrition, environmental indicators and programming targeting the first 1000 days.
- Advocacy for policies and systems to reduce air pollution: Partner advocacy efforts of youth groups and NGOs with UNICEF youth programs such as upshift, start-up, podium, U-report and ponder and other national and bilateral programs such as GIZ Prospects for Youth, USAID Demilgeluu Jashtar for increasing awareness of air pollution health impacts and empowering youth to have a voice in solutions. Maintain an online resource of audiovisual material for awareness-raising and information on health impacts and best mitigation practices for use in teacher training colleges, medical education and in schools in Bishkek.

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

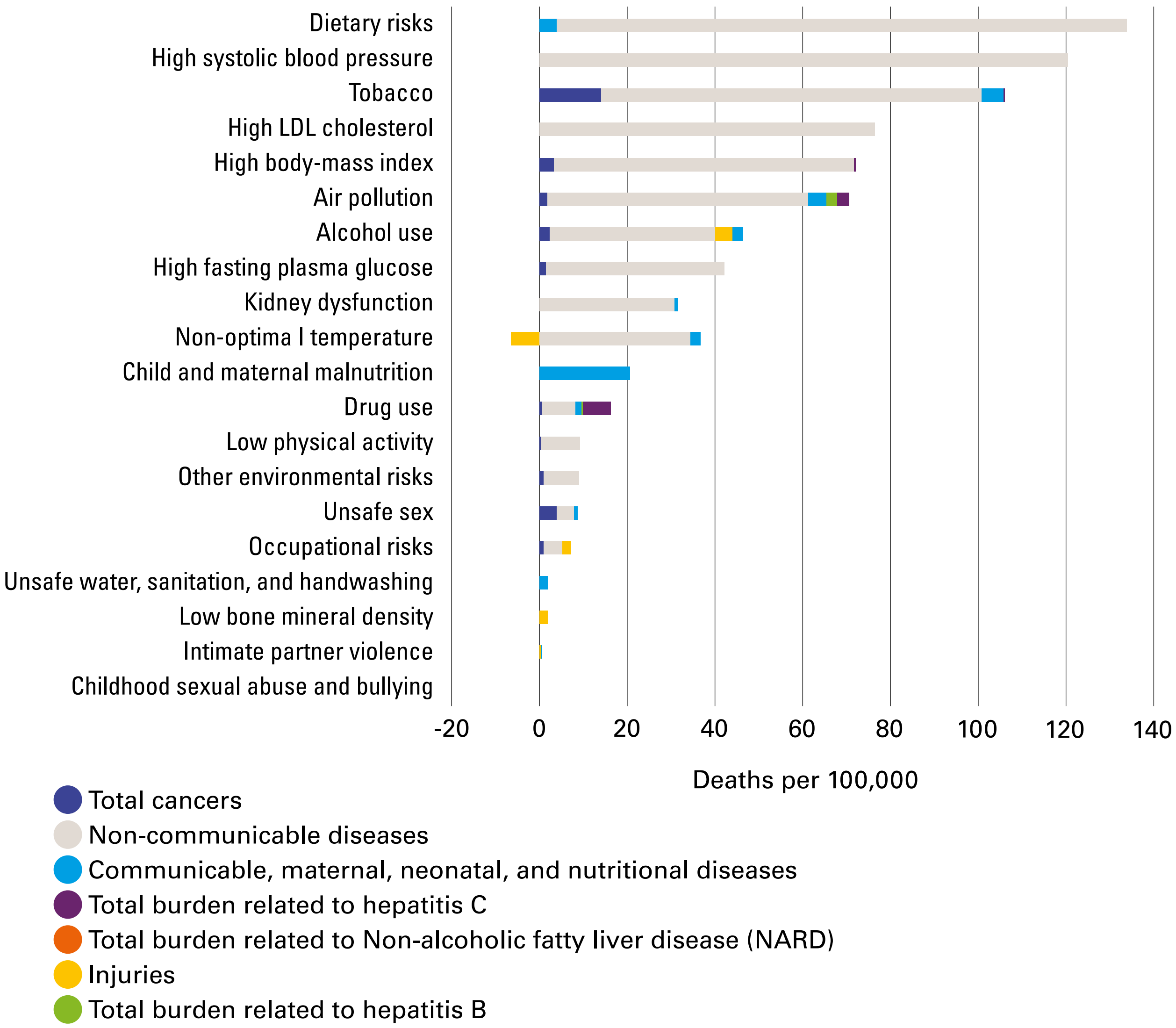
INTRODUCTION

1. INTRODUCTION

Air pollution is one of the great killers of our time[1]. There is now broad consensus that air pollution is the most significant environmental cause of disease and premature death in the world today and puts an enormous financial burden on societies. Globally, air pollution accounted for approximately 12% of all deaths, and currently ranks fourth among major risk factors for global disease and mortality, only behind hypertension, smoking and dietary factors in 2019 IHME Global Burden of Disease estimates[2]. Exposure to ambient air pollution increases mortality and morbidity and shortens life expectancy[3]. Air pollution causes ischemic heart disease, cerebrovascular disease (ischemic stroke and hemorrhagic stroke), lung cancer, lower respiratory infections, chronic obstructive pulmonary disease (COPD), and cataract formation. In addition, there is evidence linking air pollution causally to adverse birth outcomes, cognitive impacts in children, neurodegenerative disease, lung growth, and cancers of other organs.[4] Children are at high risk of pollution-related disease and even extremely low-dose exposures to pollutants during windows of vulnerability in utero and in early infancy can result in disease, disability, and death in childhood and across their lifespan[5]. Low birth weight manifested as small for gestational age and preterm birth is a predictor for infant mortality and morbidity and increases risk of respiratory disease throughout the life-course. Effects of air pollution on low birth weight have been observed in high exposure areas e.g.[6] middle exposure e.g.[7] and low exposure areas e.g.[8], although limitations in exposure assessment have resulted in some inconsistencies in outcomes. In addition, air pollution has been linked to cognitive impacts in children, and neurodegenerative decline in older adults. Health impacts of air pollution are driven not by pollution in any one place, but by people's exposure to pollution in all the places they spend time during the day, which is driven by outdoor emissions, indoor emissions, and how the two interact, i.e., how much outdoor air pollution penetrates into living environments and how much people behaviors in indoor environments contributes to outdoor air pollution. Fine particulate matter ($PM_{2.5}$) that can penetrate deep into the lung is the primary indicator of health effects for combustion-related air pollution. More information on $PM_{2.5}$ related health effects exists than for any other pollutant, although it is recognized that for some diseases it may be an indicator of combustion pollution in general and that other pollutants may play roles in health effects. There are well documented causal relationships between short term and long-term exposures to ambient $PM_{2.5}$ air pollution and major health impacts in the population, even at low concentrations, which are discussed below and more fully in Appendix 10. As a result, sustained reductions in exposures in the places the population lives and spends most of its time are required to reduce health impacts, rather than weekend trips to the mountains. Similarly, urban planning that places street canyons parallel to the predominant wind direction, is not a measure that will sustainably mitigate the health impacts of air pollution, as it doesn't account for the stagnant conditions with inversions, which combine with high localized emissions to cause high pollution episodes in winter. Although children are at particularly high risk, WHO air quality guidelines recognise that every individual benefits from cleaner air, even in places which already have low pollution concentrations[9]. Thus, measures are required to reduce average exposures of all people in the urban area in addition to reductions for those exposed to high levels, as a result of known socioeconomic inequities and increased vulnerability[9].

In Kyrgyzstan air pollution is the single biggest environmental risk factor for premature death, greater than all other environmental risks combined, and Figure 7 shows that air pollution is the

6th biggest risk factor for mortality based on IHME 2019 Global Burden of Disease estimates[iii]. While air pollution is a major cause of mortality as a result of non-communicable disease, this is under-recognized in Kyrgyzstan, and the WHO case for investment in prevention and control of noncommunicable diseases in Kyrgyzstan does not mention air pollution as a risk factor or consider air pollution interventions in the measures to reduce non-communicable disease[iv]. Biomass smoke exposure is clearly linked to COPD morbidity, and both short-term and long-term exposures to ambient air pollution are associated with mortality and morbidity due to COPD around the world, even at levels below the current air quality guidelines[10]. Similarly, air pollution exposures are linked to morbidity and mortality from myocardial infarction, hypertension, congestive heart failure, arrhythmias, ischemic stroke, and long term effects on lung cancer[5]. In addition there are also additional emerging causal relationships between ambient $PM_{2.5}$ air pollution and several other highly prevalent non-communicable diseases including diabetes, decreased cognitive function, attention-deficit or hyperactivity disorder and autism in children, and neurodegenerative disease including dementia in adults[5].



Source: Institute for Health Metrics and Evaluation, 2022.

Figure 7. IHME Causes of mortality in Kyrgyzstan by risk factor 2019.

iii Global Burden of Disease Study 2019 (GBD 2019) Results. Institute for Health Metrics and Evaluation (IHME), 2020. Available from https://vizhub.healthdata.org/gbd-results/

iv https://apps.who.int/iris/handle/10665/351407

In terms of economic burden, the estimated global health-related external costs of air pollution (i.e., those costs borne by society as a whole) were US$ 5 trillion in 2013 with an additional US$ 225 billion in lost labour productivity[v]. In addition to economic burdens of air pollution related mortality, morbidity and treatment costs, air pollution also has a significant impact on both domestic and international tourism with each incremental 1 μg/m³ increase of $PM_{2.5}$ reducing domestic and inbound tourist arrivals in China by 0.482 per cent and 1.227 per cent, respectively[11]. Tourism was listed as one of Kyrgyzstan's priority growth sectors of the Kyrgyz economy[vi]. While the need to develop other economic priorities is frequently mentioned alongside discussions about the affordability of measures to reduce air pollution, in the US the associated monetized benefits of decreased mortality, lower medical expenditures for air pollution-related diseases, and higher productivity of workers were around 30 times greater than the costs of the Clean Air Act[12]. Thus, although significant investment is required to reduce air pollution to levels that minimize health impacts in the population, the measures result in net improvements of economic growth and population welfare.

The Kyrgyzstan government has made significant initial steps both to improve baseline health in the populations, and also to start to address air pollution in Bishkek. Significant progress has been made in reducing under-5 mortality from 65.8 deaths per 1,000 live births in 1990 to 21.1 in 2016, through improvements in undernourishment and ~50% decrease in prevalence of tuberculosis between 2000 and 2012, resulting in the country achieving the Millennium Development Goal No. 4 on reducing mortality among children under five in 2015[vii] . Kyrgyzstan has developed Law of the Kyrgyz Republic "On the Protection of Atmospheric Air" including standards for atmospheric air quality and associated instructions where economic entities are required to have structural units (or staff units) responsible for atmospheric protection and conducting (or organizing) control measurements of the amount and composition of pollutant emissions[viii]. Guidance has been developed on maximum allowable and average daily concentrations of pollutants in the atmospheric air of populated areas under Decree of the Government of the Kyrgyz Republic No. 201 "Maximum permissible concentrations of pollutants in the atmospheric air of populated areas" Appendix 17, April 11, 2016. Instruction on protection of atmospheric air includes provisions for economic entities to reduce emissions during adverse meteorological conditions under direction from local governments together with the state service for monitoring the level of environmental pollution[ix].

Table 3 Ambient air quality standards in Kyrgyzstan and WHO Air quality guidelines and interim targets

Ambient Air quality Standards Kyrgyzstan (μg/m³)[b]			WHO airquality guidelines and interim targets(μg/m³)						
					IT-1	IT-2	IT-3	IT-4	AOG
$PM_{2.5}$	annual	25	$PM_{2.5}$	annual	35	25	15	10	5
	24-hour	35		24-hour[a]	75	50	37.5	25	15
PM_{10}	annual	40	PM_{10}	annual	70	50	30	20	15
	24-hour	60		24-hour[a]	150	100	75	50	45
Sulfur Dioxide	Average daily concentration	50	Sulfur Dioxide	annual					
(SO_2)	Maximum permissible concentration	500	(SO_2)	24-hour[a]	125	50			40

v https://documents.worldbank.org/en/publication/documents-reports/documentdetail/781521473177013155/the-cost-of-air-pollution-strengthening-the-economic-case-for-action

vi https://www.climate-laws.org/geographies/kyrgyzstan/policies/strategy-for-the-sustainable-development-of-the-industry-of-the-kyrgyz-republic-for-2019-2023-and-action-plan

vii https://www.worldbank.org/en/news/press-release/2019/06/07/kyrgyz-republic-to-gain-better-primary-health-care

viii https://www.fao.org/faolex/results/details/en/c/LEX-FAOC109413

ix https://www.fao.org/faolex/results/details/en/c/LEX-FAOC109413

Carbon Monoxide	Average daily concentration	3000	Carbon Monoxide						
(CO)	Maximum permissible concentration	5000	(CO)	24-hour[a]	7000				4000
Nitrogen Dioxide	Average daily concentration	40	Nitrogen Dioxide	annual	40	30	20		10
(NO_2)	Maximum permissible concentration	85	(NO_2)	24-hour[a]	120	50			25
Nitrogen Oxide	Average daily concentration	60							
(NO)	Maximum permissible concentration	400							

[a]99th percentile

[b]Maximum permissible concentrations of pollutants in the atmospheric air of populated areas.

Air quality standards are the cornerstone of air quality management[x]. Table 3 shows ambient air quality standards in Decree of the Government of the Kyrgyz Republic No. 201 "Maximum permissible concentrations of pollutants in the atmospheric air of populated areas" Appendix 17, April 11, 2016. Kyrgyzstan regulations include particles with a median aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), which show the strongest relationships with chronic disease impacts, and particles with a median aerodynamic diameter less than 10 μm (PM10), that reflect more crustal dust sources. The regulations, however do not specify the reference method, or equivalent reference methods, that are allowable in determining compliance with the standard, and the percentile that is equivalent to compliance with the 24 hour standard. Updating and modernizing regulations is an important step, as $PM_{2.5}$ particle size fractions show the strongest linkages to health impacts in the population. Similar to the WHO AQGs and interim targets, the standards should also specify that the annual average take precedence over the 24-hour average, but meeting the 24-hour standard protects against peaks of pollution that would otherwise lead to substantial excess morbidity or mortality[xi].

The Kyrgyzstan "Instruction on protection of atmospheric air" includes provisions that vehicles must be tested for emissions compliance in accordance with established standards before sale and during periodic inspections by state control bodies. Current regulations rely on outdated Russian standards from 1975 to 1987, GOST 17.2.2.03-87, which defines the contents of carbon monoxide and hydrocarbons in burnt gases of vehicles with gasoline engines, and GOST 21393-75, which covers black smoke emission from vehicles with diesel engines, while Russia itself along with other countries in the Caucasus region have moved to implement EURO standards. Since the abolishing of a vehicle inspection system[xii], however, it is unclear if routine monitoring of emissions is yet to be implemented. Historically in the Caucasus region there has been little attention in terms of policy making and compliance systems[xiii] resulting in a lag in implementation and monitoring. Routine monitoring of mobile source emissions on an annual or semi-annual basis remains an important tool for control of air pollution in western industrialized nations. Dynamometers to routinely determine vehicle emissions allow for significantly polluting vehicles with a mechanical malfunction in the vehicle fleet to be detected. Experiences in other nations have shown that the 10% of malfunctioning vehicles in the vehicle fleet contribute 90% of the emissions, which can be controlled through vehicle emissions testing.

x https://apps.who.int/iris/handle/10665/345329

xi https://apps.who.int/iris/handle/10665/107823?search-result=true&query=air+quality+guidelines&scope=&rpp=10&sort_by=score&order=desc

xii https://www.jica.go.jp/english/our_work/social_environmental/id/asia/central/kyrgyz/c8h0vm0000anzlqt.html

xiii https://rec-caucasus.org/publication/fuel-quality-and-vehicle-emission-standards-overview/

In addition to mobile sources Kyrgyzstan also has instructions establishing state control over emissions from stationary sources[xiv], and maximum allowable emissions to the atmosphere for enterprises[xv], although the primary reporting entities are the enterprises, and it is not clear that the technological, regulatory and enforcement structures to support these laws are sufficient. Experience in other countries has shown, that independent monitoring of emissions from economic entities typically by the Environmental Protection Agency is required on a routine basis, combined with real-time emissions reporting from larger facilities. Continuous reporting of data from large scale industrial facilities with on-site air pollution monitoring for $PM_{2.5}$ will become a necessity.

Kyrgyzstan has also initiated environmental priorities in several of its development strategies. Although unfortunately the National Development Strategy 2018-2040 mentions air pollution only once as an objective of expansion of green space, improvements in accountability and reporting of environmental pollution, combined with measures targeted at improving energy efficiency in power generation, reducing transmission loss, and promotion of renewable energy sources were components of the National Strategy of Sustainable Development for the Kyrgyz Republic 2013-2017, and the subsequent goal of ensuring pollution levels were not damaging to the health of the population in the Sustainable Development Strategy in Industry (2019-2023). Further, with growing global calls for a reduction in carbon emissions, and to support transition to a green economy, Kyrgyzstan formed a Coordination Council on Green Economy and Climate Change in 2020 with the Climate Finance Centre as its Secretariat[xvi], to coordinate combined activities of the Climate Investment Program (2018), and the Green Economy Development Program (2019-2023).

Kyrgyzstan in cooperation with ADB has initiated improvements in the thermal power generating facilities in Bishkek consisting of the Power and District Heating Rehabilitation Project (1996), Power Sector Improvement Project (2010), Power Sector Rehabilitation Project (2012), and Toktogul Rehabilitation Phase 2 Project (2014) Toktogul Rehabilitation Phase 3 Project[xvii]. Combined with this, Kyrgyzstan has also developed a "Plan of Comprehensive Measures to Improve the Environmental Situation in Bishkek City and Sokuluk, Alamudun districts of Chui region for 2021-2023" (Air-quality Plan) with 40 indicators with a wide range of air pollution intervention measures that focus on:

- Transition from coal to natural gas in Boiler houses (heat only boilers), residential buildings, public baths, saunas, health centers, private sector and production facilities
- Increasing piped gas networks to settlements
- Conversion of vehicles to gas fuels
- Conversion of the coal fired power plant to gas, and reducing gas costs to consumers
- Energy efficiency measures

The plan also calls for improvements in monitoring that focus on:

- automatic stations for monitoring atmospheric air pollution
- emissions testing of businesses
- emissions testing of vehicles

xiv https://www.fao.org/faolex/results/details/en/c/LEX-FAOC095711

xv https://www.fao.org/faolex/results/details/en/c/LEX-FAOC095223

xvi https://www.switchtogreen.eu/green-and-circular-growth-a-uniting-vision-for-the-kyrgyz-republic/

xvii https://www.adb.org/projects/documents/kgz-toktogul-rehabilitation-ph3-rrp

In addition, the plan calls for:

- a communication and awareness campaign
- enforcement measures

Although there are a wide range of measures, prioritization of these measures based on modelling the cost effectiveness in reducing health impacts has not been performed and thus the overall impacts on both air quality and the health of the Bishkek population is unclear.

While the government of Kyrgyzstan has taken initial steps to start addressing air pollution, outlined above, there is room for modernization of monitoring and evaluation frameworks, improvement in eHealth data, coordination, and cohesion of measures under a long-term urban master plan to map primary energy choices to different geographic areas of Bishkek over the next 10 years. Given the urgency posed by increasing air pollution concentrations in the city, reducing air pollution to levels that pose minimal health risk to residents will require political motivation, population awareness, significant investment and strategic coordination to transition households to clean energies integrated with national energy development priorities and pricing structures. Each country and city face specific challenges that are unique to their national or local context, but common air quality management challenges include: (i) weak institutional capacity and arrangements; (ii) inappropriate policies, strategies, and supporting regulations; (iii) lack of reliable baseline data; (iv) lack of awareness regarding the health and environmental impacts of air pollution; (v) lack of knowledge about, willingness to adopt, and access to process improvements and cleaner technologies; (vi) lack of a technology transfer program; and (vii) absence of financial support, incentives, and innovative financial mechanisms or approaches.[xviii] Kyrgyzstan is currently a lower-middle-income country with a gradually expanding economy and decline in external funding. With finite resources to address air pollution it is important to prioritize actions with the highest benefit-cost ratio to society, guided by an evidence-based assessment of sources, disease burdens and health inequities to target the most vulnerable populations, particularly women and young children. Prioritizing measures in the Air-quality Plan based on the highest benefits cost ratio will allow a focusing of activities around reducing health impacts in the population, combined with focusing resources on those activities with the greatest impact. Reducing pollution involves balancing costs of complying with the policy and the benefits to society such that the benefits to society exceed the marginal costs of pollution abatement. There are several critical steps in this process which include: 1) evaluating the policy context; 2) determining the health and economic burdens of air pollution in the city; 3) evaluating spatial air pollution concentrations across the city and their historical trajectories; 4) determining source sectoral contributions; 5) Modelling the impacts of price structures, incentive-based policies and piloting clean technologies; and 6) developing a communication strategy to increase awareness of the importance of addressing air pollution in the city, and the steps needed to address it. Building on the ambient air pollution evaluation conducted by the Government of Kyrgyzstan in conjunction with UNEP and UNDP[xix], the current study provides a baseline for the first 3 of these steps, and recommendations for entry points for the others. This study responds to one of the Air-quality Plan's indicators to to provide the most robust assessment to date of health impacts of air pollution in Bishkek and inform the development of appropriate disease prevention measures.

xviii https://www.adb.org/projects/documents/reg-51347-001-tar

xix UNDP and UNEP (2022). Air Quality in Bishkek: Assessment of emission sources and road map for supporting air quality management. Bishkek & Nairobi.

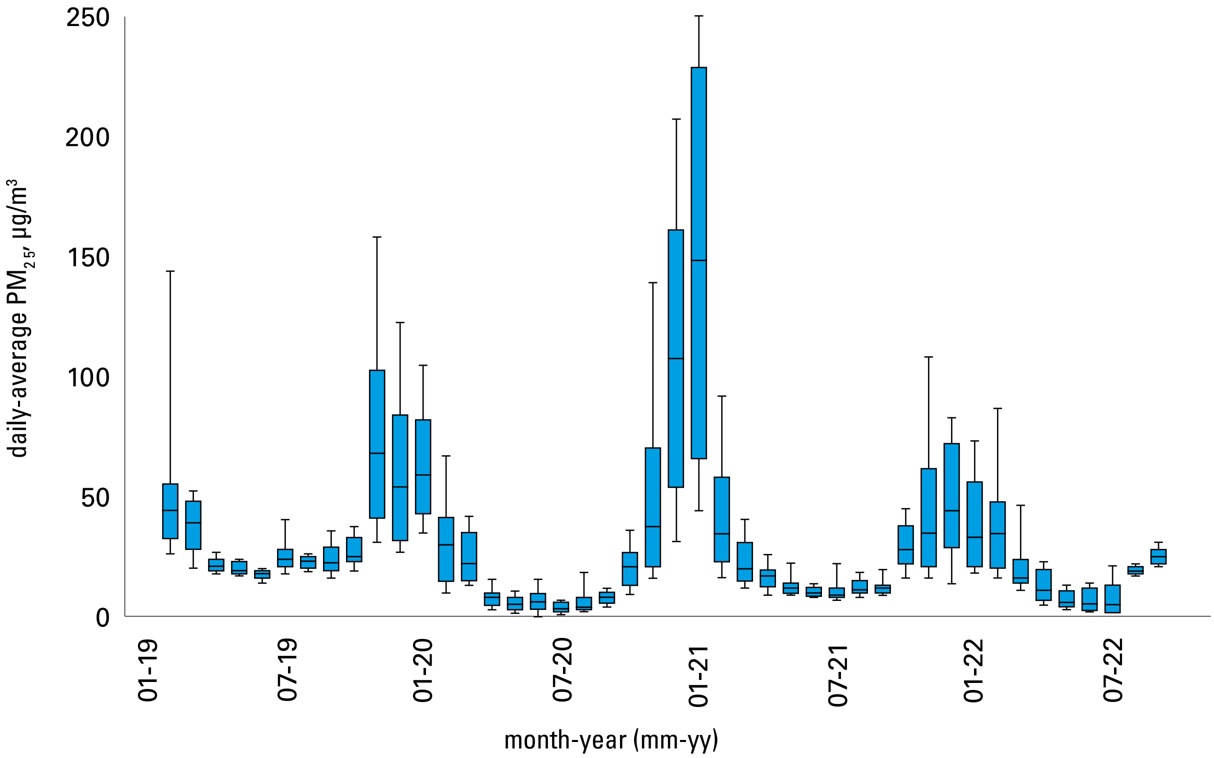
The objectives of the current project were to: 1) Perform a rapid situation analysis of the current air quality policy frameworks in Bishkek city by conducting interviews with government ministries, multilateral organizations, advocacy organizations including youth and community groups, and other stakeholders, to identify the role innovative technological solutions, youth advocacy and multisector partnerships can play in reducing health impacts. 2) estimate current health impacts from air pollution in Bishkek; 3) estimate economic consequences of inaction on air pollution; and 4) make recommendations on a strategy for cost effective prioritization of measures to reduce air pollution to mobilize a sustained movement towards policy change with short-term, mid-term and long-term objectives.

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

BACKGROUND TO ENERGY TRANSITIONS IN BISHKEK

2. BACKGROUND TO ENERGY TRANSITIONS IN BISHKEK

Bishkek suffers from high levels of air pollution during cold winter heating seasons, and on some days has been reported to top the list of the world's most polluted cities[xx]. In 2019 The U.S. Embassy in Bishkek installed Beta attenuation monitors (BAM; MetOne Model 1020) used in the U.S. State Department global $PM_{2.5}$ monitoring network, which has U.S. EPA Federal Equivalent Method (FEM) designation. Although, the US state Department Monitor was operational starting in 2019, and the Hydromet monitoring station produced intermittent data between 2019-2022, which makes it hard to evaluate, the largest uncertainty is how both monitors represent the spatial variability of $PM_{2.5}$ concentration across the city. In spite of being located in a low concentration area of the city, however, the State Department monitoring site clearly shows in Figure 8 that wintertime concentrations are far in excess of those known to have major adverse health effects in urban populations. The absence of high concentrations in non-heating periods combined with the high correlation with sulfur emissions from residential heating coal[xxi] also indicates that residential space heating is a dominant cause of poor air quality during the wintertime.



Source: U.S. State Department monitor, Bishkek, 2022.

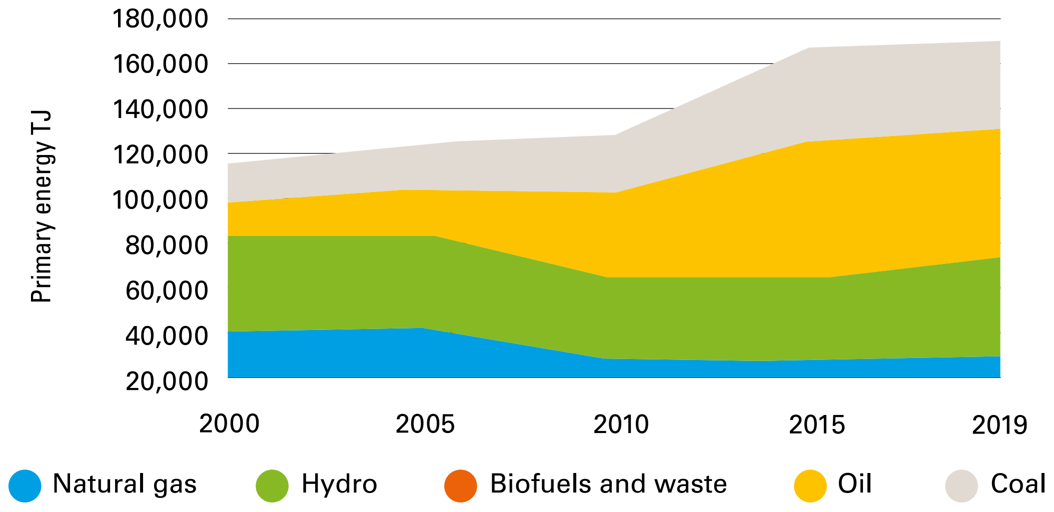
Figure 8 $PM_{2.5}$ concentrations measured at the U.S. Embassy Bishkek.

xx https://www.thethirdpole.net/en/pollution/record-breaking-air-pollution-chokes-bishkek-and-almaty/

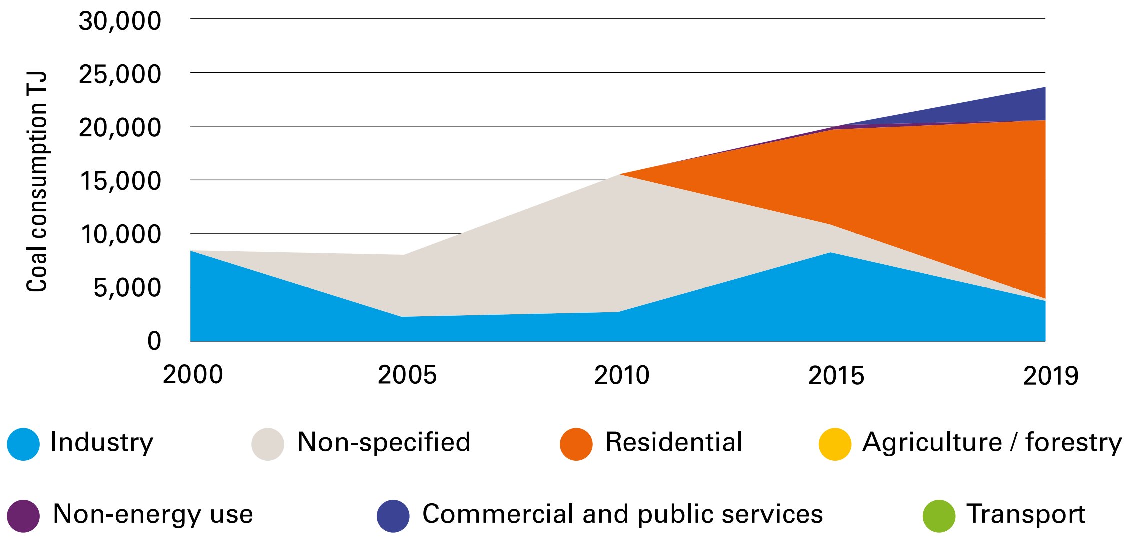
xxi UNDP and UNEP (2022). Air Quality in Bishkek: Assessment of emission sources and road map for supporting air quality management. Bishkek & Nairobi.

A significant factor in the feasibility of transition to clean household fuels is the cost and availability of clean alternatives, including foreign reserves required to acquire fuels that are imported. Energy policy aims to improve energy security by developing indigenous energy sources and rehabilitating and expanding transmission and distribution networks, and Kyrgyzstan is part of the EU4Energy Program, which is focused on evidence-based policymaking in the energy sector. Aging infrastructure and distribution systems in both thermal and hydroelectric generation result in significant losses, which have been targeted in a sequence of projects in cooperation with ADB[xxii]. Figure 9 shows the total energy supply by source and coal consumption by sector in Kyrgyzstan. Although Kyrgyzstan has a significant but relatively static renewable hydroelectric generation, with substantial potential for expanded supply, the last 10 years has seen large increases in oil and coal supplies for primary energy, and energy consumption patterns demonstrate a substantial increase in residential coal combustion for residential space heating which coincide with poor air quality in urban areas.

a)



b)

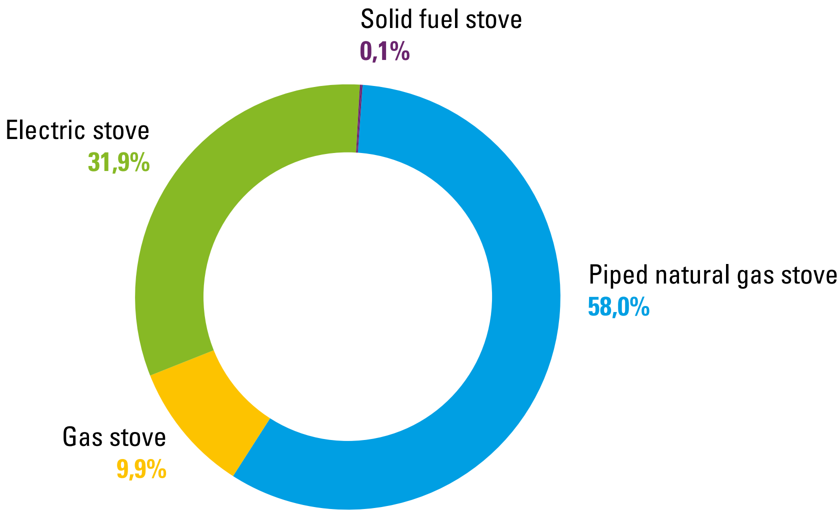


Source: IEA

Figure 9 a) Primary energy supply by source and b) coal consumption by sector for Kyrgyzstan.

xxii https://www.adb.org/projects/documents/kgz-toktogul-rehabilitation-ph3-rrp

Household air pollution is principally the result of cooking, space heating and lighting. Figure 10 shows that in Bishkek primary fuels used for lighting and cooking are gas and electricity reported in the population-based UNICEF Multiple Indicator Cluster Survey (MICS 2018), which are classified as clean fuels at the household level. There is little doubt that electricity and gas pose much lower risks to children than the use of solid fuels in these households, although there is a growing body of evidence to support links between short term exposures to NO_2 from gas cooking and increased asthma morbidity in children[13], and long-term exposure to NO_2 and development of asthma in children14.



Source: MICS 2018

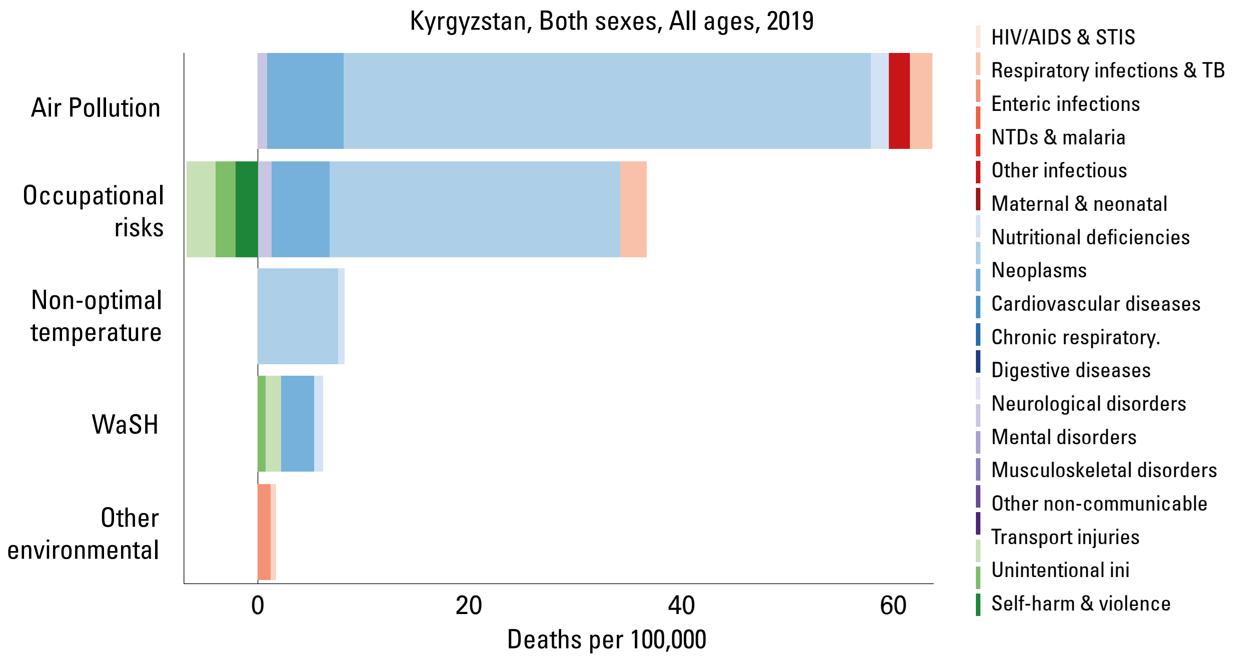
Figure 10. Principal cooking fuels in homes in Bishkek

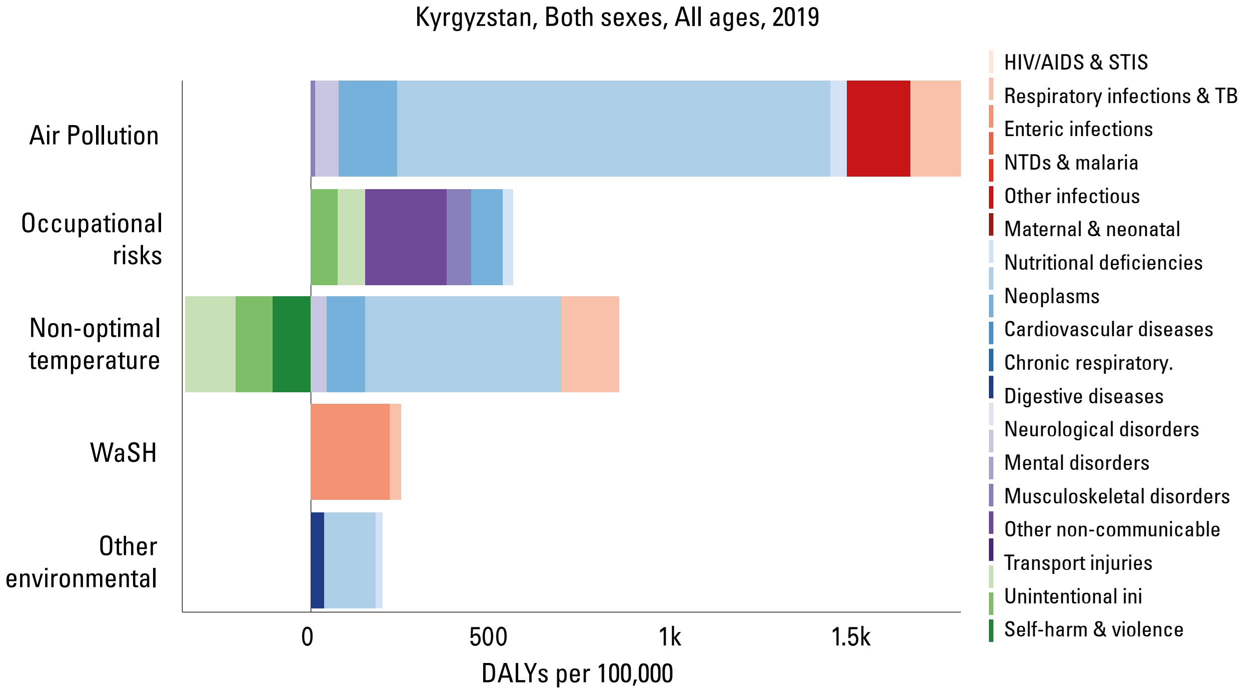
Table 4 below shows the percentage use of different fuels as a main fuel for space heating needs in winter in Bishkek, and wider Kyrgyzstan reported in MICS 2018. Primary fuels for space heating in Bishkek was supplied predominantly by central heating, lignite coal, electricity and to a lesser extent gas. Within wider Kyrgyzstan analysis by wealth quintiles shows that lignite coal is used largely by poorer populations in stoves with chimneys, and the richest quintile uses mostly clean fuels. Household fuel use in Bishkek from MICS 2018 only collects information on the primary fuel used and does not include current initiatives to extend gas distribution networks in the last 2 years. Experiences around the world indicate that frequently fuels are "stacked" in homes, and multiple fuels and stoves are used for both heating and cooking. While there is some use of coal stoves for some cooking tasks, and use of secondary stoves for cooking and space heating in Bishkek, this is not quantified in MICS 2018. As a result, collecting more in-depth information on the use and cost of secondary fuels was an important objective of the representative household survey in 1007 homes in the current study.

Table 4 Primary fuels used for space heating in Bishkek and by income quintile in Kyrgyzstan.

	Central heating	Solar air heater	Electricity	Piped natural gas	LPG/gas	Coal Lignite	Charcoal	Wood	Clean Technologies for space heating
Total	**11.6**	**0.2**	**6.5**	**1.2**	**0.3**	**70.3**	**4.3**	**2**	**19.6**
Urban	31.3	0.3	12.4	3.2	0.7	49.7	1.6	0.5	48
Rural	0.4	0.1	3.1	0	0	81.9	5.8	2.9	3.6
Bishkek city	46	0.4	7.8	4.5	1.2	39.9	0.1	0.1	59.9
Poorest	0.5	0.2	1.3	0	0.1	82.3	4.2	4.8	2
Second	0.1	0.1	2.9	0	0	80.7	7.6	3.2	3
Middle	0.3	0	5.8	0.3	0	82.5	4.9	1.7	6.6
Fourth	1.1	0.2	7.2	1	0.1	83.6	4.1	0.3	9.6
Richest	55.7	0.4	15.1	4.6	1.2	22.5	0.4	0.1	77

Figure 11 shows the IHME burden of disease in death and disability adjusted life years (DALY) attributable to environmental risk factors in Kyrgyzstan for the latest year 2019. Air pollution is the single biggest environmental risk factor for premature death in Kyrgyzstan, greater than all the other environmental risks combined. With limited resources to address environmental risks, the analysis demonstrated the need to mobilize action to reduce air pollution exposures in the population. Law No. 51 on "protection of atmospheric air" states that citizens have the right to atmospheric air favorable for life and health. Figure 6 demonstrates that with more than 4,158 deaths and 117,000 DALYs attributable to air pollution in 2019 alone this is far from the current reality.

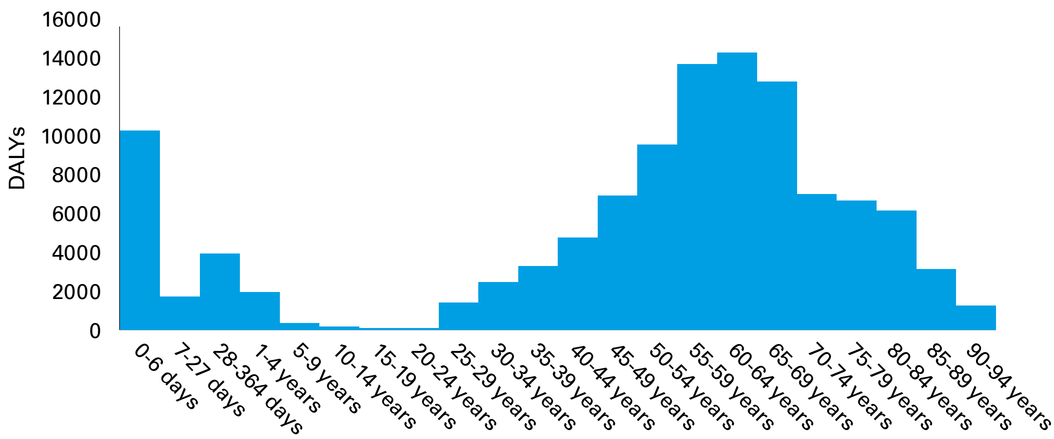


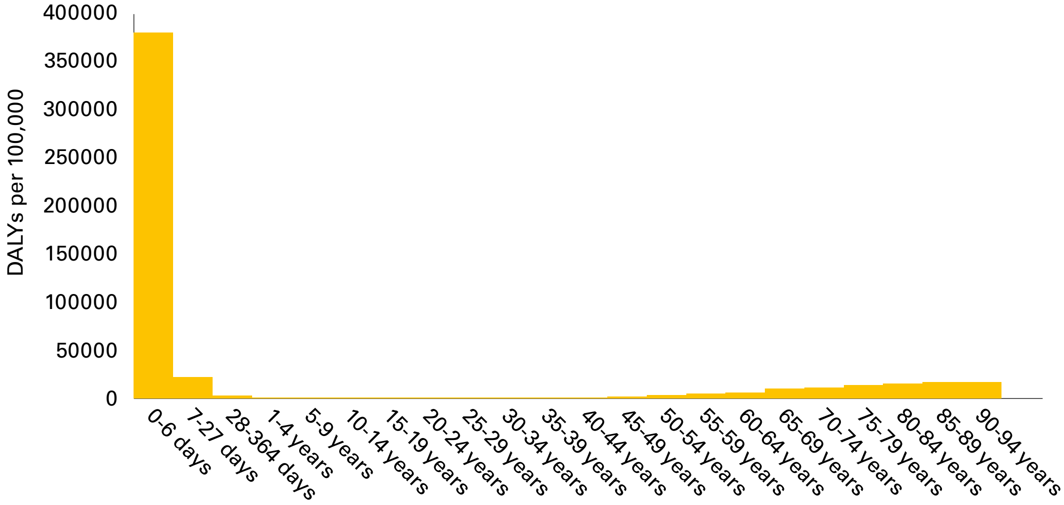


Source: Institute for Health Metrics and Evaluation, 2019.

Figure 11. IHME burden of disease in death and disability adjusted life years (DALY) attributable to environmental risk factors in Kyrgyzstan for 2019

Like many health impacts from environmental causes, Figure 12a shows that health impacts of air pollution are not distributed equally across the population. The absolute number of DALYs attributable to air pollution are high immediately after birth with the greatest impacts in the first 6 days, with a decline through childhood. Subsequently impacts of air pollution increase with age to peak around 60 years old, and decline with lower population numbers at higher ages. Figure 12b shows the rate of DALYs per 100,000, normalized by populations size in each age group, which shows that children in the days immediately after birth are most vulnerable to the impacts of air pollution and health effects are dominated by exposures to fine particulate matter ($PM_{2.5}$). Reducing these health impacts represents a clear priority, as these children would otherwise develop to lead healthy lives.



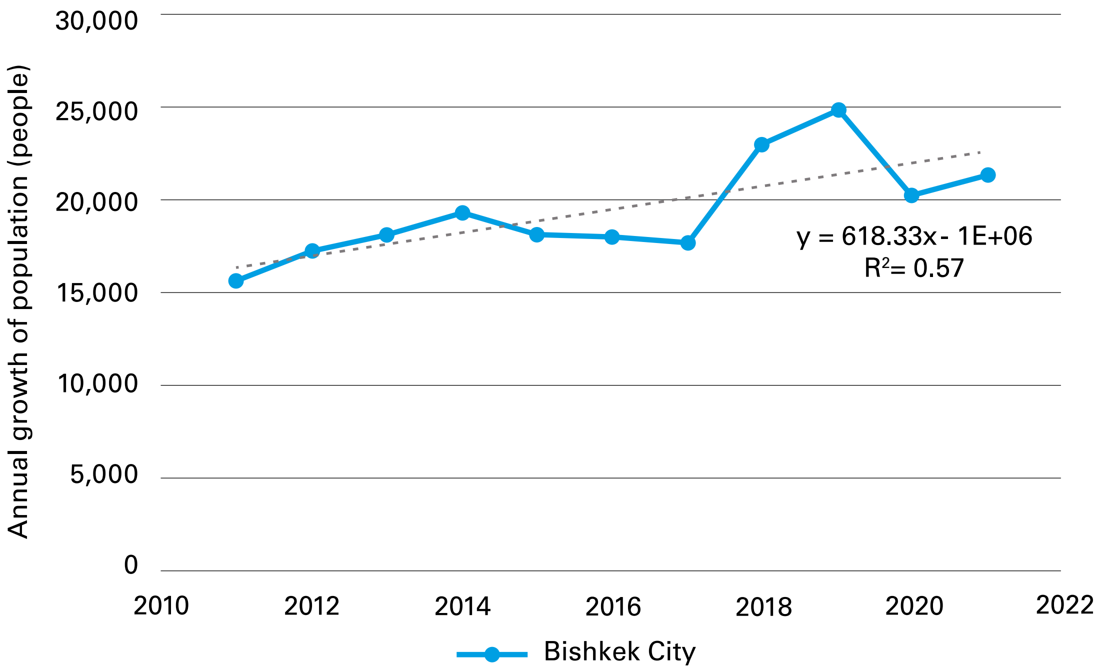


Source: Institute for Health Metrics and Evaluation, 2022.

Figure 12. DALYs attributable to air pollution in Kyrgyzstan in 2019 by age; a) DALY; b) DALY rate per 100,000

Health impacts from air pollution can be divided into those impacts from household air pollution and those impacts from ambient air pollution. In Bishkek, where a large number of homes use coal for space heating during the winter these categories are somewhat artificial as household air pollution emissions from burning raw coal contribute to ambient pollution, and in turn ambient pollution re-penetrates indoors. In neighborhoods where large fractions of homes are burning raw coal, emissions outdoors can create "neighborhood" pollution, where emissions cause a localized buildup of air pollution concentrations that are much higher than citywide averages and are not reflected in ambient fixed site monitoring data. The spatial heterogeneity of air pollution concentrations across the city, however, plays a large role in concentrations to which residents are exposed, leading to differences in age normalized health impacts in the populations in different areas. Since used of clean fuels is more prevalent in higher income quintiles of the population and burning coal in stoves more prevalent in lower income groups, the burdens of pollution are not equally distributed. Mapping this variability in air pollution concentrations across Bishkek is an important objective of the current study. It is important to recognize, however, that every individual benefits from reductions in air pollution, even in areas which already have lower pollution concentrations.

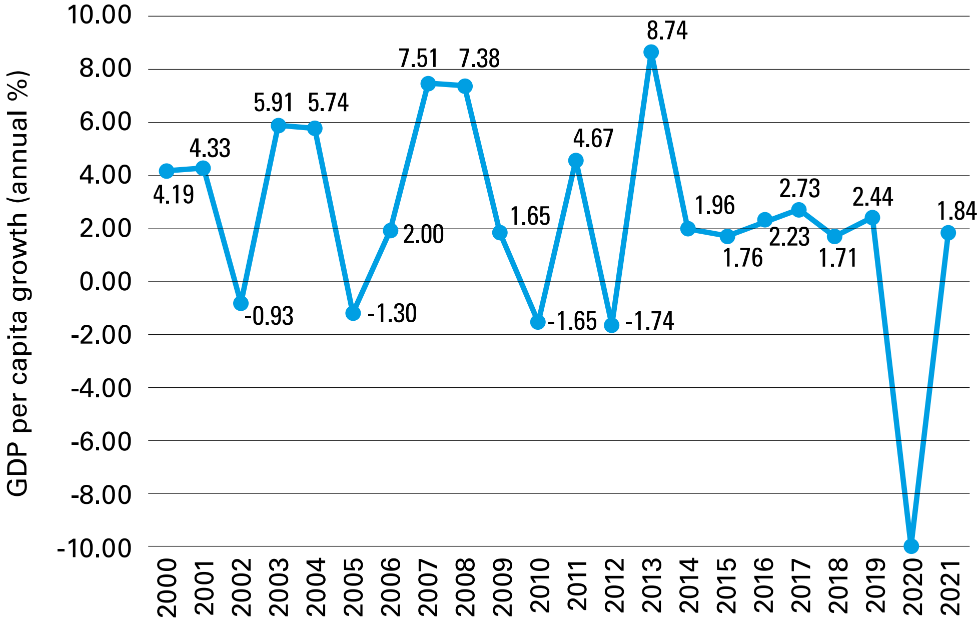
Reduction in air pollution in Bishkek by reducing the numbers of homes using raw coal for space heating sooner rather than later is a priority, as steady increase in population growth of the city and expansion beyond municipal boundaries presents an increasing challenge for air pollution control. Figure 13 shows the annual growth in the number of people that reside in Bishkek, with current growth rates in excess of 20,000 people per year.



Source: National Statistical Committee of the Kyrgyz Republic, 2022.

Figure 13. Annual growth of the population that reside in Bishkek

Kyrgyzstan is a lower-middle-income country with a gradually expanding economy. Figure 14 shows Gross Domestic Product (GDP) per capita in Kyrgyzstan has grown fairly consistently since 2014, with the exception of 2020 during the global SARS-CoV-2 pandemic. A decline in external funding underlines the importance of effective use of domestic resources combined with a long term urban master plan to map primary energy choices to different geographic areas of Bishkek to reduce air pollution to WHO air quality targets. In terms of air pollution, the increased reliance on domestic resources emphasizes the importance of prioritization of air pollution reduction measures based on cost effectiveness in reducing health burdens to maximize overall impact, and net improvements of economic growth and population welfare.



Source: World Bank

Figure 14. Percentage growth in GDP per capita

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

ASSESSMENT FRAMEWORK

3. ASSESSMENT FRAMEWORK

Although the Government of Kyrgyzstan has taken initial steps to start to address the high concentrations of air pollution experienced in Bishkek during the winter months that are far in excess of those known to have major adverse health effects in urban populations, the current evidence base to understand the consequences of these elevated air pollution concentrations on the health and social welfare of women and children in Bishkek is weak, however, due to a number of factors:

1. The spatial variability of ambient air pollution over Bishkek and surrounding areas is not well understood due to a small number of fixed site monitors with limited history and data integrity, combined with recently deployed smart sensor arrays that are not referenced to ground level concentrations.
2. Indoor air concentrations for houses using different fuel types are not well understood
3. The stacking of heating options, where multiple heating sources are used in homes, and actual costs of fuel options is not well characterized.
4. Barriers to adoption of cleaner alternatives in different population groups is not well defined
5. Validity and reliability of baseline health data for the population in Bishkek and particularly in the surrounding areas makes disease prevalence rates difficult to assess

The objectives of the current assessment respond to some of these inadequacies by collecting primary data to provide an up-to-date assessment of the health and social impacts of air pollution on women and children in Bishkek to inform the development of appropriate disease prevention measures.

To achieve this objective the assessment had the following key activities: 1. Rapid situational analysis; 2. Validated low cost sensor measurements of indoor and outdoor household air pollution; 3. Urban scale air quality assessment of $PM_{2.5}$ gradients within Bishkek; 4. Exposure and health impact assessment; 5. Household survey and contingent valuation subsample; 6. Economic analysis of impacts of air pollution; and 7. Recommendations on a strategy for cost effective prioritization of measures in the action plan based on reduced health impacts in the population to mobilize a sustained movement towards policy change with short-term, mid-term and long-term objectives.

1. Rapid situational analysis

A rapid situational analysis and stakeholder mapping was performed to assess Bishkek's readiness to accelerate access to clean energy technologies based on the WHO Household Energy Assessment Rapid Tool (HEART). Similar city level approaches have been performed under the WHO Urban Health Initiative to identify evidence-based strategies to reduce the burden of air pollution in Accra, Ghana; and Katmandu, Nepal[xxiii]; and with UNICEF in Ulaanbaatar, Mongolia[xxiv]; Prishtinë, Kosovo[xxv]; and Myanmar. As part of this assessment strategic entry points are identified through interviews with government ministries,

xxiii https://www.who.int/initiatives/urban-health-initiative/pilot-projects

xxiv https://www.unicef.org/mongolia/press-releases/unicef-calls-action-protect-children-air-pollution-mongolia

xxv https://www.unicef.org/kosovoprogramme/reports/impact-air-pollution multilateral organizations, advocacy organizations including youth and community groups, and other stakeholders, combined with an assessment of coordination mechanisms and review of policy frameworks.

2. Validated low-cost sensor measurements of indoor and outdoor household air pollution

The project use paired low-cost sensors to conduct simultaneous indoor/outdoor measurements at residences on a rolling basis to estimate exposures and neighborhood concentrations using 10 Clarity sensors calibrated against reference methods for $PM_{2.5}$ and cross validated to ensure data comparability between sensors placed in different households.

3. Urban scale air quality assessment

Continuous ground-level measurements of air pollution in urban areas in Bishkek are very limited. $PM_{2.5}$ data from existing low-cost sensor networks using the same Clarity sensors were analyzed in conjunction with the indoor /outdoor sensors to develop and quantify spatial patterns in wintertime $PM_{2.5}$ across Bishkek city. Spatial patterns in wintertime $PM_{2.5}$ across Bishkek city were also compared to ambient $PM_{2.5}$ using a hybrid model of high-resolution satellite information from multiple satellite products (MISR, MODIS DarkTarget, MODIS and SeaWiFS Deep Blue, and MODISMAIAC) a GEOS-Chem global 3D model of atmospheric to estimate historical changes in $PM_{2.5}$ across the city

4. Exposure and health impact assessment

As health impacts are driven not by pollution in any one place, but by people's exposure to pollution in all the places they spend time, these health impacts rely on estimated population exposures to $PM_{2.5}$ particulate matter. Exposure estimates combined time activity information from the National Statistics office and representative household survey data with low-cost sensor measurements of indoor and outdoor concentrations at residences using different space heating arrangements to estimate personal exposure concentrations for residents in each house in the representative household survey. Health impacts were based on dose response curves used in Global Burden of Disease (GBD) assessments for diseases acknowledged by the World Health Organization to have causal links to air pollution exposure: ischaemic heart disease (IHD), cerebrovascular disease (ischaemic stroke and haemorrhagic stroke), lung cancer, lower respiratory infections (LRI), diabetes and chronic obstructive pulmonary disease (COPD) for which non-linear exposure-response functions exist spanning the global range of exposure[15]. Although air pollution is also linked to a range of other health impacts such as adverse birth outcomes, cognitive impacts in children, neurodegenerative disease, lung growth, and cancers of other organs, there is currently insufficient evidence to include these endpoints. Exposure-response curves for particulate matter developed as part of GBD frameworks allows estimation of the health effects of air pollution exposure by age, sex and disease category.

5. Household survey

Estimation of residential indoor exposures relies on knowing the amount of time spent in the home through time activity surveys, and also knowledge of the fuel and energy choices at a household level. In addition household income, energy efficiency measure, fuel costs and knowledge of clean heating alternatives at a household level is critical in evaluating the barriers to adoption of clean technologies. To assess this information in Bishkek a representative household survey was conducted in 1007 households spatially spread across the city. The survey collected representative population data on:

- Reported monthly household income
- Housing type

- Heating type
- Heating fuel and costs
- Insulation materials
- Indoor and household tobacco smoking
- Reported health impacts and medication

6. Contingent valuation survey

In general, pollution is costly for individuals, families, and society. Pollution-related diseases cause productivity losses that reduce gross domestic product (GDP) in low-income to middle-income countries by up to 2% per year[5]. Standard methods exist to estimate the economic cost to society of mortality from air pollution, which is by far the largest component of the cost of air pollution[16]. In the United States averted deaths comprised 92.4% of economic benefits in the US from implementation of the Clean Air Act in the period 1990-2020, and about 88% of total estimated benefits[12]. The cost being estimated is the loss of life itself[17], rather than treatment costs or financial cost to a household. To estimate the cost of mortality at the level of society as a whole, the value of statistical life (VSL), derived from aggregating individuals' willingness to pay to secure a marginal reduction in the risk of premature death, is used to estimate economic costs of mortality from air pollution by multiplying the VSL by the number of premature deaths[8]. Many countries lack reliable estimates of the VSL. Although VSL adjusted for income is widely applied, locally derived estimates incorporate differences in attitudes, beliefs and knowledge of impacts. A number of factors including income elasticity can significantly affect benefit transfer including income elasticity assumptions, cultural differences and air pollution exposure characteristics[18], but the effect of these are poorly understood or unknown [19], resulting in the need for greater reliance on directly assessed values particularly for low- and middle-income countries [20]. In this study estimates derived from using a VSL from the United States adjusted for differences in income[21] are compared with locally derived estimates of VSL using a contingent valuation questionnaire approach in 600 homes to assess attitudes and willingness to pay for air pollution reductions in Bishkek.

3.1. RAPID ASSESSMENT

The government of Kyrgyzstan has initiated projects aimed at reducing air pollution in cooperation with multilateral institutions such as the United Nations, European Union, the Asian Development Bank and the World Bank, and with bilateral donors, including significant investment in gas turbines to modernize electricity generation, increasing residential gas heating networks, piloting of heat pumps, evaluating policy options, to name a few. Multilateral organizations including UNICEF, WHO, UNEP and UNDP have also collaborated with the Government to improve information on health through MICS surveys, use of ICD10 coding to track disease incidence, and increasing awareness of non-communicable disease impacts, and evaluating ambient air pollution concentrations from monitoring sites. While these initiatives are a step forward, unfortunately there are major gaps that prevent detailed evaluation of the causes of the problem and resultant health impacts in the population. Prioritization of policies based on their potential to reduce air pollution-related health impacts in the population, human resources, technical capacity, and enforcement abilities have progressed more slowly. Due to a lack of information on the factors and industries contributing to air pollution, regulations have often not been data-driven[xxvi]. There is a need to develop an Urban Master Plan to map primary energy choices to different geographic areas of Bishkek to reduce air pollution to WHO air quality guidelines, with a national budget to achieve these goals. While this is

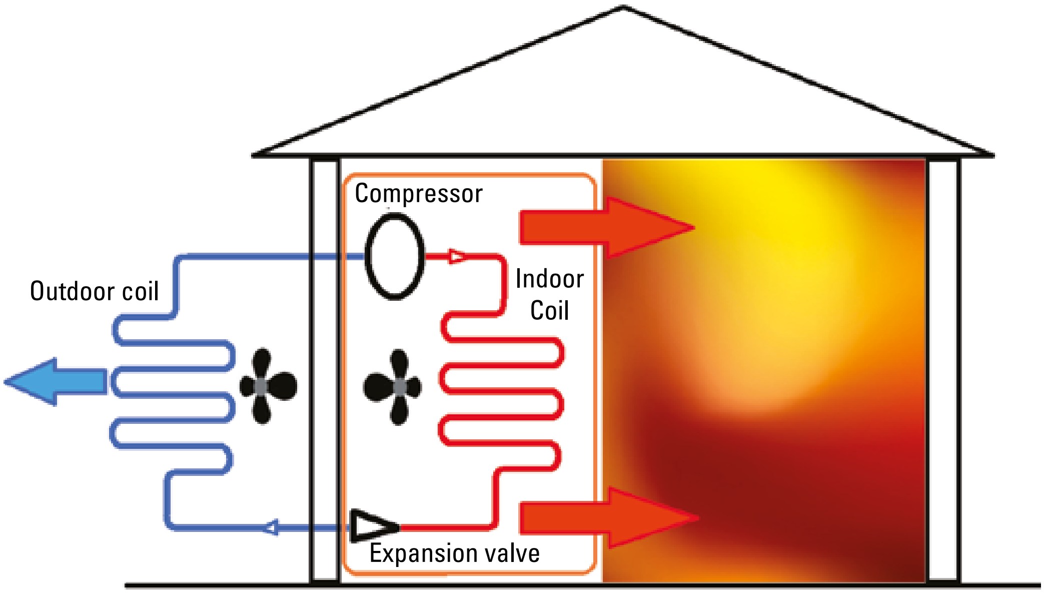
xxvi https://www.ndi.org/our-stories/combating-air-pollution-kyrgyzstan generally acknowledged by the Government and international groups, there is still a lack of systematic evaluation of the costs of different approaches, and the timeframe over which the transition would occur. Principal barriers are as follows:

Table 5. Barriers that hinder understanding of air pollution in Bishkek and effective strategies to mitigate the problem

Barriers:
• Lack of prioritization of air pollution policy measures based on cost effectiveness to reduce health
• impacts
• Modeling of policy trajectories to meet air quality objectives and desired health outcomes
• Awareness of disease burdens and health impacts of air pollution
• Awareness of sectoral contribution to air pollution problem
• Economic modellingto optimize pricing structures to increase penetration of clean household energy
• Awareness of comparativecosts of clean household energy interventions
• Retrofitting older buildings with district heatingto provide thermoregulation and allow network expansion
• Low interest loans and other financial incentives to overcome purchase price of air-to-air heat pumps
• Low interest loans and other financial incentives to overcome purchase price of natural gas connections
• Programs to reduce of exposures during pregnancy and early lifeduringthe period of energy transition
• Coordination within and between government and multilateral organizations
• Policy coherence, and enforcement of regulations and standards
• Capacity ofgovernment and multilateral organizations

Reducing the health impacts of air pollution in urban areas is only successfully accomplished through political and social awareness of the health impacts imposed by air pollution combined with allocation of appropriate resources and coordinated action across sectors. To assist government, the private sector, civil society, multilateral and bilateral organizations in resolving the air pollution problem, an urban master plan to map primary energy choices to different geographic areas of Bishkek to reduce air pollution to WHO air quality targets would assist in coordinating actions and resources. In addition, greater political awareness of the economic and social benefits of investing in intervention strategies quickly rather than more gradually, and the burdens imposed by inaction, will assist policy makers in prioritizing air pollution.

A number of clean residential heating technologies are available, which if combined with energy efficiency measures and promoted at scale would dramatically reduce air pollution in Bishkek. Principally expansion of district central heating networks in the urban center, acceleration of gas distribution networks in surrounding communities and air-to-air heat pumps installed in more dispersed communities. There are a number of barriers that currently hamper distribution at scale related to lack of awareness of the importance of these technologies in addressing the air pollution problem, as the household sector has only recently gained recognition as a major contributor to the issue, combined with lack of awareness of economic benefits of clean household technologies in comparison to coal. Furthermore there is a lack of financial incentives to incentivize households to eliminate coal stoves, combined with low interest loans or small scale financing options to overcome purchase barriers in less affluent urban communities. Installation of metering to promote energy efficiency in the network, however, provides an important mechanism to increase the number of residences served and maximize the capacity of the system to reduce emissions from homes.



Box 1 Air-to-air Heat Pumps

Conceptually an air-to air heat pump compresses a refrigerant which causes it to heat up and this heat is released in indoor environments using a fan that blows room air over the warm coils. The refrigerant is then transferred to the outdoor environment, where the refrigerant is expanded, causing the refrigerant to cool. Air from outside the house is blown by a second fan across the cold coils, causing heat energy to be absorbed by the refrigerant, even when the outdoor temperatures are cold during winter. In this way heat pumps do not generate heat – they absorb heat energy from the outside air (even in cold temperatures) and transfer it indoors. In cold environments a double or triple compressor may be used. When it's warm outside in summer months, the direction of the refrigerant can be reversed so it acts as an air conditioner, removing heat from your home. A principal advantage is a heat pump transfers heat instead of generating heat, making it much more energy efficiency compared to electric resistance heating.

3.2. EVIDENCE-BASED POLICY-MAKING

With finite resources to address pollution it is important to prioritize actions that are feasible in the current political and cultural context with the highest benefit-cost ratio to society, guided by an evidence-based assessment of sources, disease burdens and health inequities to target the most vulnerable populations, particularly women and young children. Reducing pollution involves balancing cost of complying with the policy and the benefits to society such that the benefits to society exceed the marginal costs of pollution abatement. Air pollution also has a quantifiable impact on GDP and other key macro-economic indicators[22]. While the need to develop other economic priorities is frequently mentioned alongside discussions about the affordability of measures to reduce air pollution, analyses of the benefits and costs of the U.S.

Clean Air Act in the period 1990-2020 indicate that although the United States spent 65 billion U.S. dollars on air pollution reductions, the benefits exceed the costs by a factor of 3012. Evaluation of policies to promote economic growth in Bishkek should incorporate impacts on air pollution emissions and resultant impacts on health and tourism. As Kyrgyzstan transitions to a lower-middle-income country with a gradually expanding economy and decline in external funding, the need to implement tools that allow prioritization of policies based on cost effective use of limited resources is a priority. Current air pollution monitoring and health data in Bishkek does not provide an adequate evidence base for policymaking.

Health Data

The quality of health data and measures undertaken to digitize health reporting are documented in the WHO situation analysis on evidence-informed health policy-making Kyrgyzstan 2020[xxvii]. Primary health care in the Kyrgyz Republic has progressively advanced under the national health-care reforms: Manas (1996–2006), Manas Taalimi (2006–2010) and Den Sooluk (2012–2018), followed by the implementation of e-Health Strategy of the Kyrgyz Republic for 2016-2020, and Healthy person – prosperous country 2019–2030[xxviii] aimed toward development of public health including health systems and more cost-effective use of resources, supported by the World Bank healthcare improvement project[xxix]. Briefly, there are two main routine health data reporting systems in the country - health statistics, and data from the mandatory health insurance fund. The MoH e-Health Center collects health statistics data from both primary care facilities and hospitals using a combination of paper and electronic reporting modes. The health statistics primary care data are mainly collected using a patient level clinical reporting form for the first visit and any follow-ups within a week, which are submitted to a facility level health statistics office for entry into the Access-based desktop application for submission to regional e-Health centers and subsequently to the e-Health Center in Bishkek, where the regional data are consolidated to produce national level data.

Major efforts have been made to improve and integrate health information systems and introduce modern e-health technologies. The e-Health Strategy and Action Plan 2015–2020 has as its ambition a modern computerized health-care system based on coordinated development of central and local systems, and consolidation of previously fragmented system[xxx]. At present the process of electronic data entry timely at the appointment and transfer to the central database was only present in some clinics, and in others data entry was still performed by a separate unit from paper records[23]. Ultimately, as Kyrgyzstan progresses to point of contact health data entry, there are a number of barriers to the use of health data for evidence-based policy making on a systematic basis for Bishkek city based on air pollution related epidemiologic endpoints, but availability of these databases provide a critical tool for evaluating policy impacts.

1. Consistency

Although the intent is to have an integrated health information system, there are still several parallel streams of information collection as well as reports of major differences in the validity and reliability of data. For example the World Health Organization Regional Office for Europe Quality of care review in Kyrgyzstan: working document (2018)[xxxi] reports parallel

xxvii situation analysis on evidence-informed health policy-making Kyrgyzstan EVIPNet Europe Series, No 4. https://www.who.int/europe/publications/m/item/situation-analysis-on-evidence-informed-health-policy-making.-kyrgyzstan--evipnet-europe-series--no-4-(2020)

xxviii https://www.who.int/europe/news/item/23-01-2019-kyrgyzstan-adopts-new-health-strategy-for-2019-2030

xxix https://www.worldbank.org/en/news/press-release/2019/06/07/kyrgyz-republic-to-gain-better-primary-health-care

xxx https://www.who.int/europe/publications/m/item/situation-analysis-on-evidence-informed-health-policy-making.-kyrgyzstan--evipnet-europe-series--no-4-(2020)

xxxi https://apps.who.int/iris/handle/10665/345601 reporting systems give conflicting results, such as for immunizations and Hospital doctors perform clinical ICD 10 coding without computer assistance or systematic recoding. Without systematic recoding inconsistencies may occur between hospitals and between primary health care facilities and city hospitals, and different prevalence of indiscriminate dump codes may lead to significant errors in prevalence estimation. A 2022 study indicated that the biggest inaccuracies were the discrepancies in coding practices between physicians[23]. Insufficient level of knowledge and skills among family doctors combined with low prestige of family doctors and shortage of doctors willing to work in primary health care combine to make confidence of coding outcomes on the clinical reporting form used by family doctors low. Variability between years of the relative incidence of diseases that should remain consistent with in defined populations[xxxii] is a significant indicator of low reliability in coding outcomes. Increased training on ICD10 coding for doctors engaged in primary health care is therefore a priority particularly in relation to coding related diseases that have a distinctly different etiology. In addition to coding consistencies, under reporting in less affluent populations as a result of reluctance to report to medical facilities due to affordability of co-payments for medication, and cause of death attribution for those in outlying areas of the city may also result in bias in health reporting for air pollution related outcomes. Among the 2.3 million individuals who required medical assistance in 2015, 31.8% did not access any health services, and financial hardship related to the cost of health services is common with 39% of total health expenditure out-of-pocket in 2014[24].

2. Accuracy

While beyond the scope of the current project, the World Health Organization Regional Office for Europe Quality of care review in Kyrgyzstan: working document (2018)[xxxiii] outlines several inconsistencies that present a significant barrier to conducting systematic epidemiological research to support evidence based policy evaluation. Prevalence of non-specific dump codes for diseases related to air pollution which do not discriminate between similar conditions that may vary in causes, such as differences between bacterial and viral pneumonia and ischemic vs hemorrhagic stroke make attribution of health impacts of air pollution an issue of expert judgement. Similarly, a key barrier reported in data collection process in Kyrgyzstan is that unique identifiers for individuals are given on the clinic level, and individuals visiting different clinics will get a different code in each clinic[23].

3. Coverage area

The areas with higher $PM_{2.5}$ air pollution concentrations in Bishkek are on the periphery of the municipal boundaries. Since much of the informal housing areas are outside municipal boundaries and these are the populations most vulnerable to the effects of air pollution there is potential for significant underestimation of health impacts from these informal areas as the health outcomes are not directly reported and included in citywide estimates

4. Data accessibility

While the website of the National Statistical Committee of the Kyrgyz Republic presents a range of statistical data including morbidity and mortality[xxxiv], Access to data associated with

xxxii https://apps.who.int/iris/handle/10665/345601

xxxiii https://apps.who.int/iris/handle/10665/345601

xxxiv http://www.stat.kg/en/opendata/

primary ICD10 codes would facilitate much broader investigation of health trends in addition to those conducted by the Department of State Sanitary–Epidemiological Surveillance. Coding related to surveillance of air pollution related outcomes would include total mortality for cardiovascular diseases (ICD-10 codes I00–I99), stroke (ICD-10 codes I60–I69), cardiac diseases (ICD-10 codes I00–I09 and I20–I52), respiratory diseases (ICD-10 codes J00–J98), and cardiopulmonary diseases (ICD-10 codes I00–I99 and ICD-10 J00–J98). For air pollution related morbidity hospital respiratory outpatients data is required for six specific respiratory diseases (acute upper respiratory infections, ICD-10 codes J02-J06; pneumonia, J18; other acute lower respiratory infection, J20-J22; other diseases of upper respiratory tract, J30-J39; chronic lower respiratory diseases, J40-J47; and other respiratory diseases, J60-J99). In addition disorders of newborn related to slow fetal growth and fetal malnutrition codes P07.0–P0.73 preterm births ICD-10 codes P07.0–P07.3 and short for gestational age ICD-10 codes P07.0–P07.3 are typically identified as health outcomes

Research budgets

Evidence based policy making requires an organizational framework to deliver robust results to policymakers. Budgets for research and development in Kyrgyzstan in 2020 were 0.09%, considerably lower than comparative countries. Table 5 shows global expenditure on research and development as a function of income.

Table 6. Global research and development expenditure as a percentage of GDP[xxxv]

Income	Latest year reported	Percentage of GDP
High income	2020	3.0
Upper middle income	2020	2.0
Middle income	2020	1.9
Lower middle income	2017	0.5

In addition to the total amount of funding, there are also considerations in the prioritization of research to achieve social benefits. The appropriateness and relevance of research projects becomes more critical with limited government financial resources for scientific research. In 2017 of 29 health related topics put forward by the Ministry of Education and Science to be financed most were still very clinically oriented and only 3 included some component of environmental health on assessment of COPD etiology, mercury contamination and counteracting the tuberculosis epidemic. There were no projects aimed at assessing the impacts of the severe air pollution currently experienced in urban areas.

In 2018, the Department of Science, under the Ministry of Education and Science released for public discussion a list of priority scientific disciplines for the years 2018-2022 with the following specific areas for research[xxxvi]:

1. Efficient use of natural resources.
2. Food security.
3. Information Technologies.
4. Health and quality of human life.
5. Efficient use of energy resources.

xxxv https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS

xxxvi http://unece.org/sites/default/files/2021-03/STI%20gap%20analysis_Kyrgyzstan_Report_%20Aziz%20Soltobaev.pdf

6. Tourism and transport logistics.
7. Public and humanitarian sciences.

While the list includes health and quality of human life which would encompass research on the health and economic impacts of air pollution, the list has not been approved by the cabinet and a final document defining current priority scientific research established[xxxvii].

The National Academy of Sciences conducts research and advises the government in matters of scientific policy and to disseminate scientific knowledge. The Academy has three major departments including one focusing on medical sciences. The Ministry of Health established the Scientific Technical Committee in August 2019 to coordinate medical research activities under the State Committee on Science, as the funder and the final decision-maker in grant allocation[xxxviii]. At present it is not clear the extent to which formal mechanisms for coordination between institutions exist in setting research priorities. In addition formal mechanisms for selection of grants based on independent peer review, such as are practiced by the US and Europe, or access to independent review through European Science Foundation (ESF) College of Expert Reviewers should be a priority for transparent selection of proposals based on merit.

In addition to increasing the research budgets and administrative oversight, research support infrastructure at universities needs to be developed to allow efficient use and management of research funds.

3.3. HOUSEHOLD SURVEY POPULATION, INCOME AND FUEL USE

The household survey was conducted using a Tablet Assisted Personal Interview for 1007 households from 50 polling stations with the individual most knowledgeable on the subject of winter heating and fuel cost, and 601 randomly selected individuals in the household using an automated randomized selection from household members for the hypothetical contingent valuation between 26th of April 2022 and 26 May 2022. Figure 15 shows the distribution of survey polling areas around Bishkek city. A team of 26 interviewers were trained at M-Vector offices prior to the study including research objectives organization and conduct of interviews, Discussion of each question of the questionnaire and explanation of the 2 stages of the interview. Household selection outcomes are shown in Appendix 9. The majority of failures to secure responses from the household were related to direct refusal at the threshold (406) reluctance to reveal income (307) and from lack of anyone answering the door (356) or house abandoned (128). While acceptance or refusal if based on systematic perceptions may bias the representativeness of survey outcomes, age and income distributions closely matched expected population distributions based on MICS and census data. Post survey quality control was assessed on voice recordings of interviews (household survey 198; contingent valuation 121) and through telephone contact with the household respondent (household survey 266; contingent valuation 142).

xxxvii http://unece.org/sites/default/files/2021-03/STI%20gap%20analysis_Kyrgyzstan_Report_%20Aziz%20Soltobaev.pdf

xxxviii https://www.who.int/europe/publications/m/item/situation-analysis-on-evidence-informed-health-policy-making.-kyrgyzstan--evipnet-europe-series--no-4-(2020)

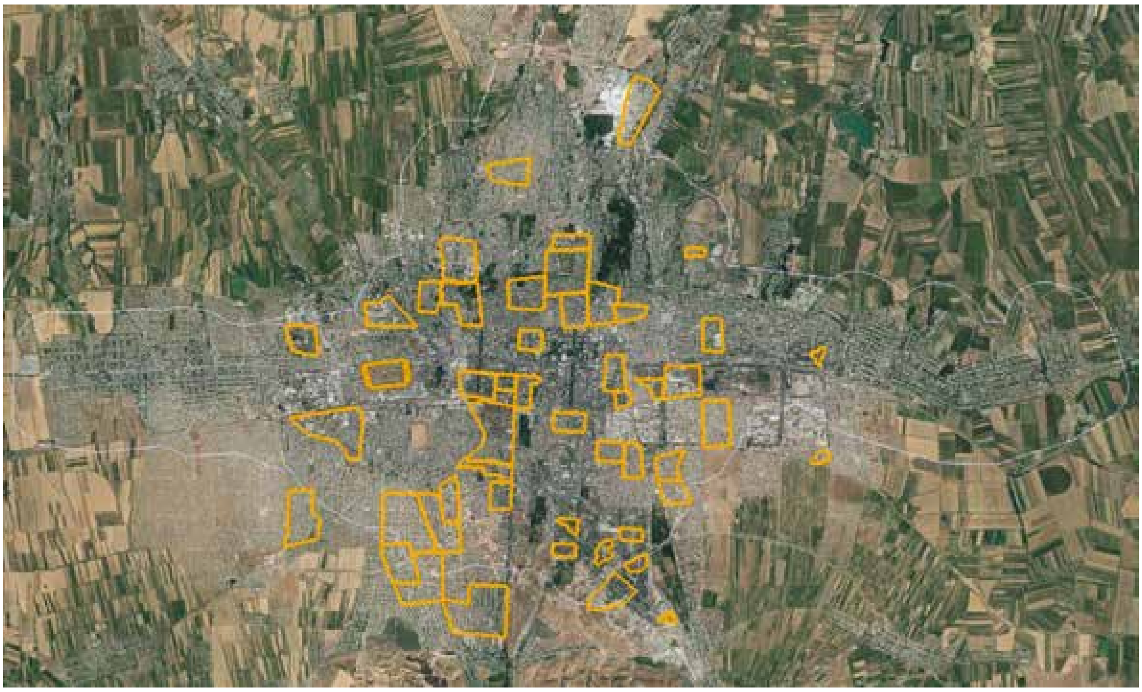


Figure 15 Distribution of survey polling areas around Bishkek city.

Housing type

Figure 16 shows Housing types in the household survey are largely split between apartment buildings and one story detached homes.

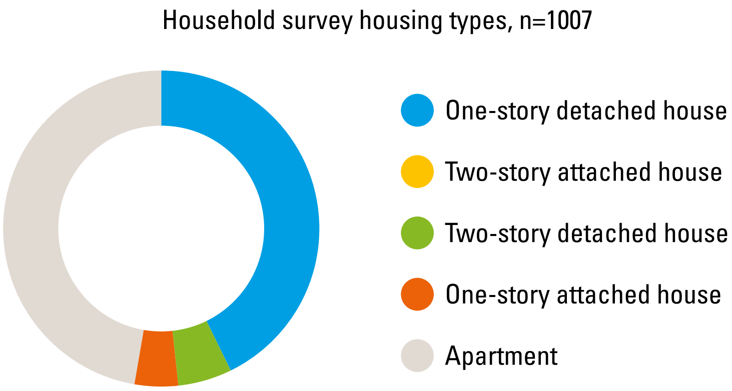


Figure 16 Housing types in Household survey

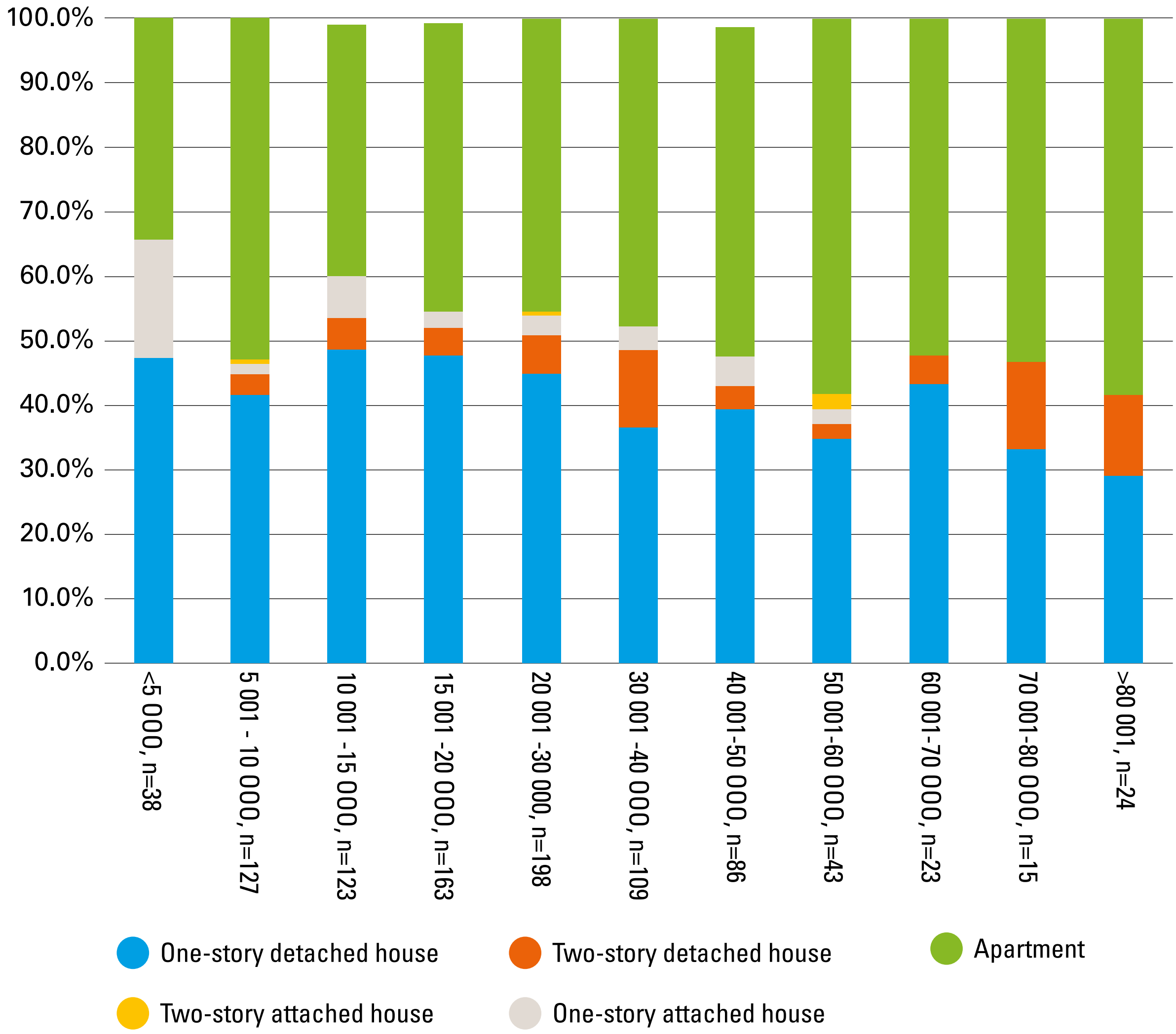


Figure 17. Housing type by total monthly household income

When categorized by household income (Figure 17) apartments and two-story homes are generally more frequent at upper income strata and one story detached and attached homes more prevalent in less affluent populations

Heating type and fuels

Figure 18 shows over a quarter of households used coal stoves burning raw coal as main heating fuels, and almost half households used central heating. Since MICS 2018 Central heating increased by 2.1% to 48%, electric heating increased by 0.4% to 8.2%, piped gas central heating increased by10% to 14.5%, individual gas stoves increased by 1% to 2.2% and use of coal in stoves decreased by 13.7% to 26.2%. This latter reduction in particular represents a significant move in the right direction, although much still remains to be done.

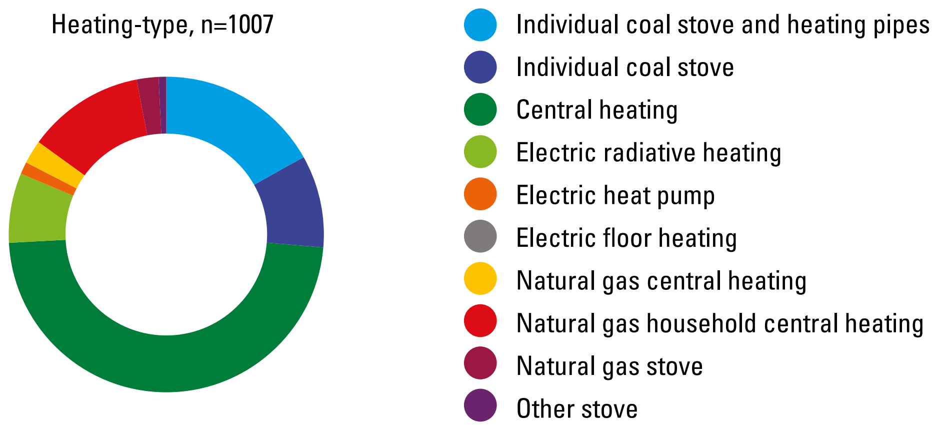


Figure 18 Primary source of winter space heating

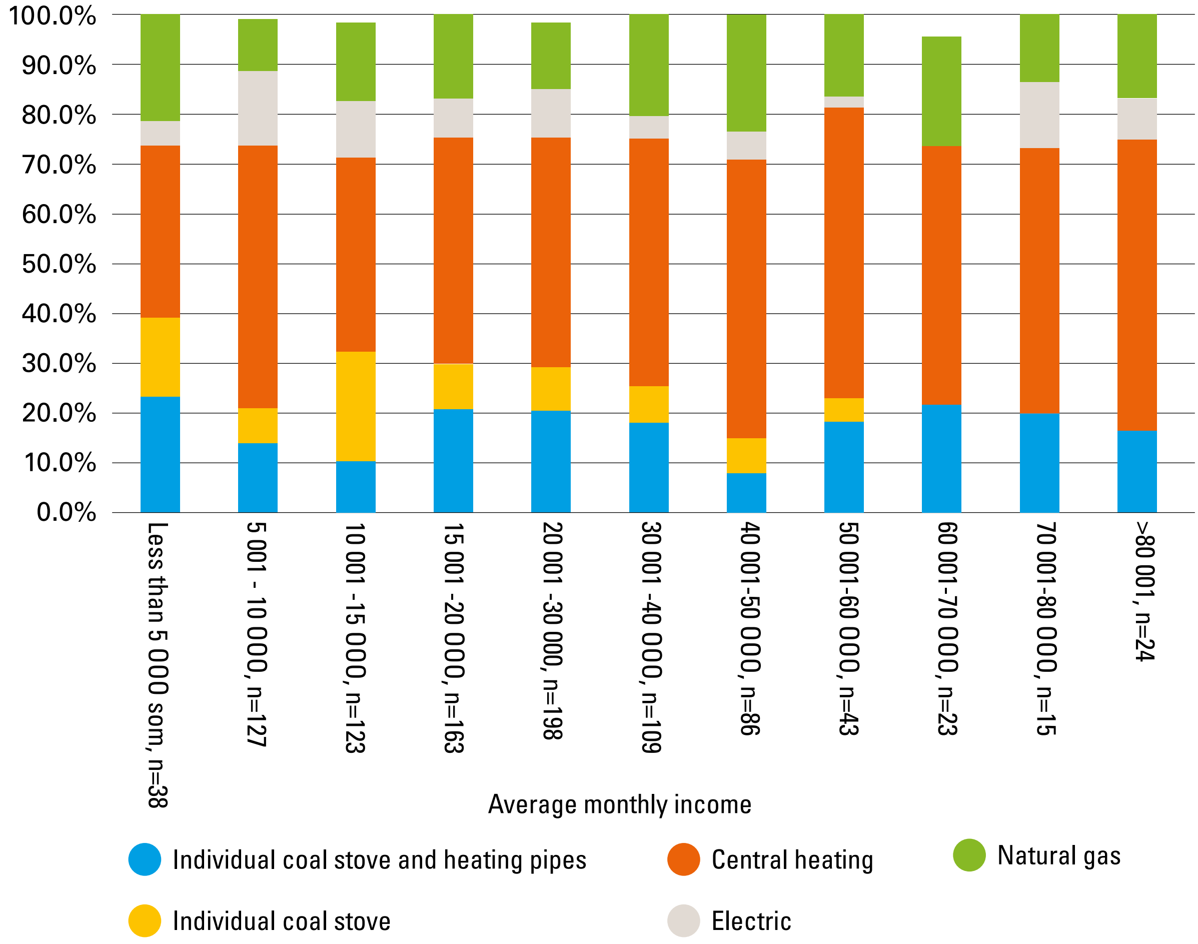


Figure 19 Primary source of winter space heating by total monthly household income

When categorized by income (Figure 19), although a modest trend in increasing central heating with income is observed, and a decrease in individual coal stoves that are not connected to radiator pipes, the relatively high prevalence of coal stoves in upper income strata represents a clear target for clean fuel intervention efforts, given that price and affordability are lower constraints in these groups. Since many homes that use individual stoves use more than 1 fuel, Figure 20 shows the distribution of additional heating fuels in households.

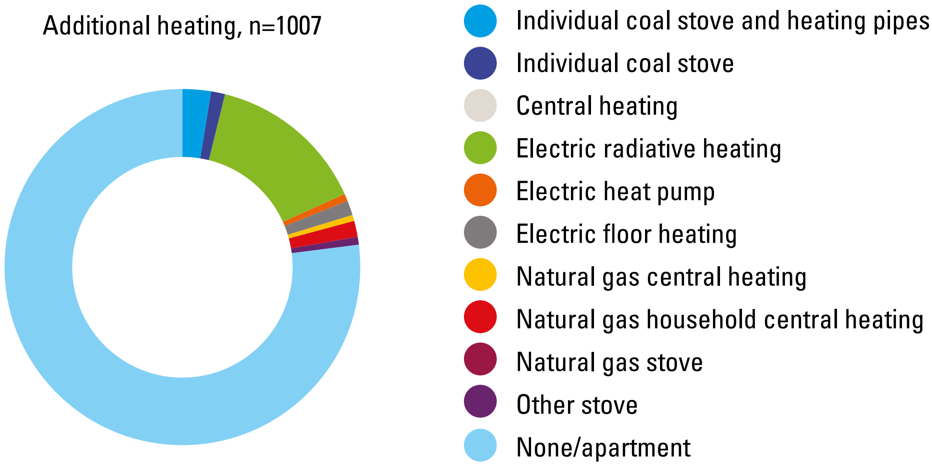


Figure 20 Secondary source of winter space heating

Figure 21 demonstrates that approximately 1/3 of homes with stoves only use coal and 2/3 use more than one fuel with the majority using tree trunk wood. Stoves using wood and charcoal as primary fuels also used coal as a secondary fuel. While in the questionnaire it was possible to list more than one secondary fuel, there was not a large overlap and approximately 1/3 of homes with stoves did not use a secondary fuel. Use of garbage, and wood off-cuts and lumber was reported with relatively low prevalence.

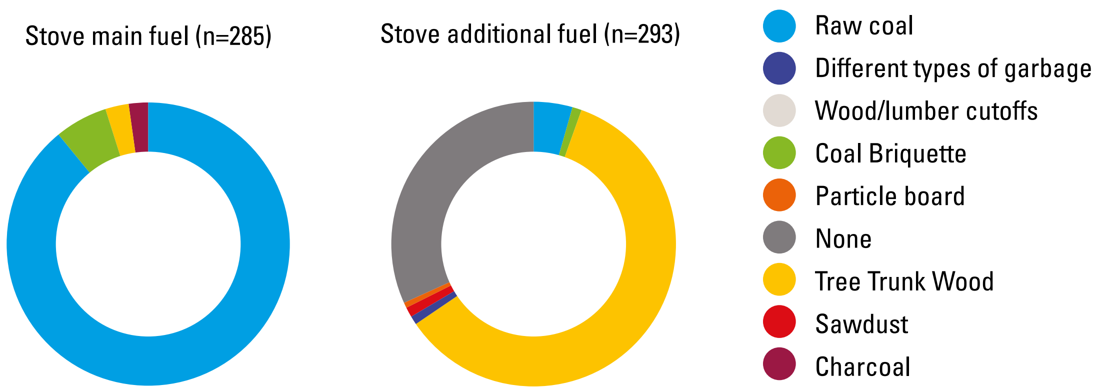


Figure 21 Primary and secondary fuels used for winter space heating in stoves

Energy Efficiency

Figure 22 shows the fraction of homes with roof insulation and wall insulation. Apartment buildings were not included due to the lack of individual control over the building envelope and knowledge of the construction present. In general the striking aspect of these graphs is that 59% and 56% have no insulation on housing walls and housing roofs respectively. Energy conservation remains an important priority for reducing energy demand and ensuring affordability of clean options. Clean household heating options should be combined with efficiency measures in incentive packages to reduce energy costs to homeowners.

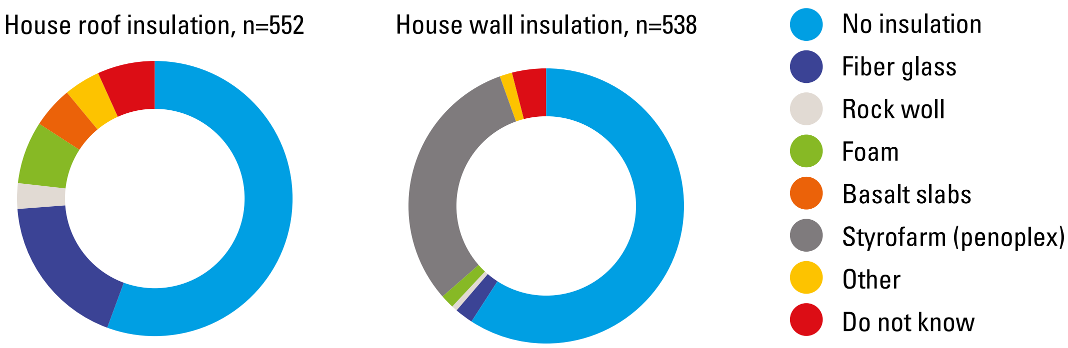


Figure 22 Fraction of homes with roof insulation and wall insulation

For homes that reported no insulation there is a clear trend with income in Figure 23 which demonstrates that incentive packages are required to target low-income populations. It is also clear that even at the highest income strata there are significant deficiencies in home insulation that should be targeted through communication and awareness campaigns.

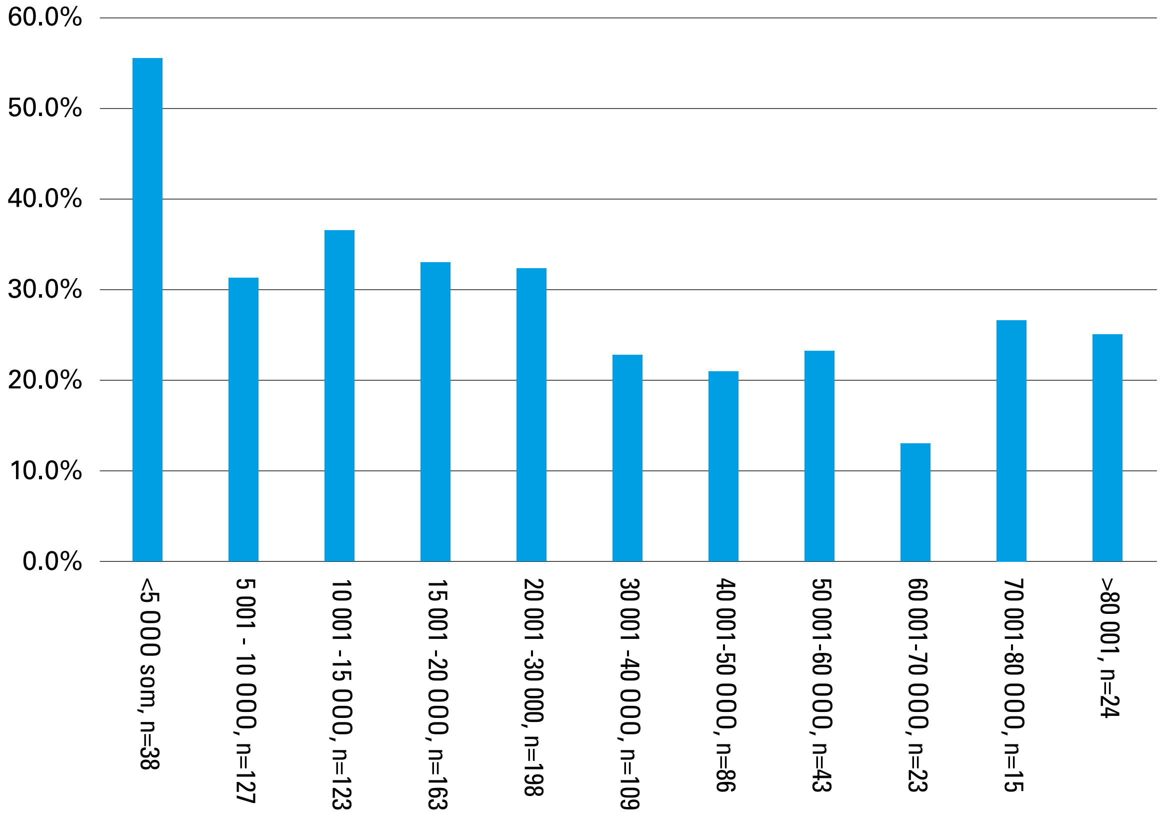


Figure 23 No home insulation by total monthly household income

Window panes

Similarly Figure 24 shows the prevalence of double and triple glazing on windows in relation to income. In general as income strata are higher there is a higher prevalence of modern plastic windows with double glazing. There is still significant potential for improvement of energy efficiency even at higher income strata through elimination of single pane windows and older wooden windows.

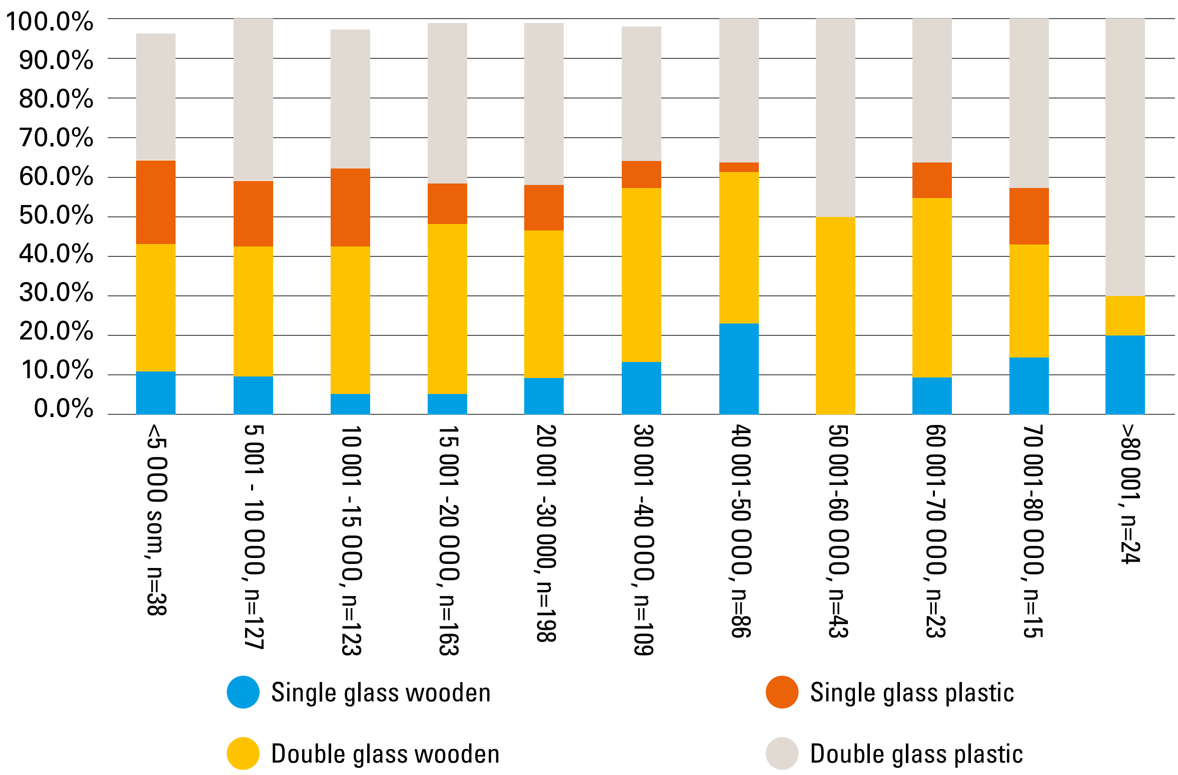


Figure 24 Prevalence of double and triple glazing on windows in relation to total monthly household income

Power outages

Reports of power outages in the last week in households was relatively low with 75.9% reporting no outage and 7.6 reporting they didn't know of any. Use of clean household heating sources, however, relies on consistent delivery and voltage of electricity and mitigation of supply chain issues for the 16.2% of homes that reported outages remains a priority

Perceptions and knowledge about clean heating options

Figure 25 shows the perceptions of the most knowledgeable of the household residents about use of solar panels and heat pumps. In general householders indicated that they lacked information about clean heating alternatives with 63 % indicating they didn't know enough about solar and 72% indicating they didn't know enough about air-to-air heat pumps. While cost was an issue for about half of household for solar (47%), a quarter indicated they didn't know (26%). In contrast approximately equal fractions thought cost was and issue for air-to-air heat pumps (41%), or indicated they didn't know (37%). Not surprisingly given summertime temperatures in Bishek, 74% indicated they would have much more interest in an air-to-air heat pump if it provided air conditioning during hot summer days, which was reflected in the population interested in having an air conditioner in their home (70%). Overall the responses indicate that knowledge about clean household options is a major barrier to acceptance, and that provision of cooling may be a significant attraction to overcoming adoption of air-to-air heat pump technologies.

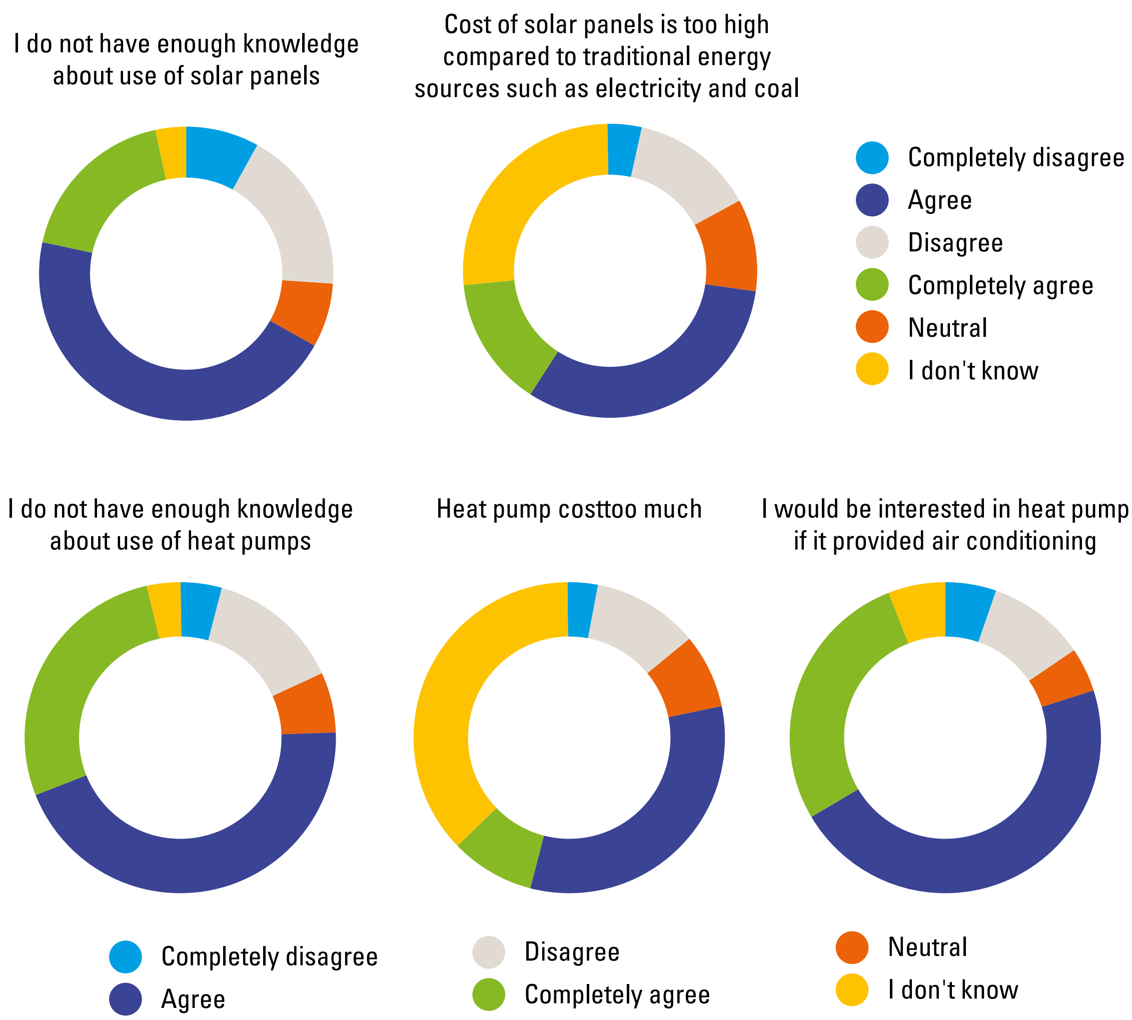


Figure 25 Perceptions of household residents about use of solar panels and heat pumps

Communication strategies to capitalize on increase availability of trusted information are a priority for increasing the fraction of clean household technologies, combined with increased awareness of the benefits of energy efficiency measures in reducing running costs.

3.4. AMBIENT $PM_{2.5}$ CONCENTRATIONS

Figure 26 shows annual average $PM_{2.5}$ concentrations for the ADB/Kyrgyzhydromet Clarity sensor network for the period July 2021-June 2022. Network data were validated and censored to remove sites with less than 50% daily data completeness for one or more of the three seasons (Winter = November-January; Summer = April-September; and Transition = February, March, and October), which resulted in a reduction in number of sites from 49 to 37. Clarity Sensor data were bias adjusted using US Embassy Bishkek reference monitoring data.

There is high variability across the City of Bishkek and annual average $PM_{2.5}$ concentrations vary by a factor of four across the network (17-75 µg/m^3), with concentrations lowest in the south and central business districts consistent with prevailing southerly winds during the winter, intermediate in the east and west districts, and highest in the north. Across the city of Bishkek, therefore, residents are exposed to annual average concentrations that range from moderately elevated to far in excess of concentrations known to cause major health impacts in populations. High spatial variability highlights the impacts of burning raw coal in residential heating on $PM_{2.5}$ gradients across the city, and also highlights the difficulties in siting fixed monitoring sites to obtain representative concentrations across the city for health impact estimation.

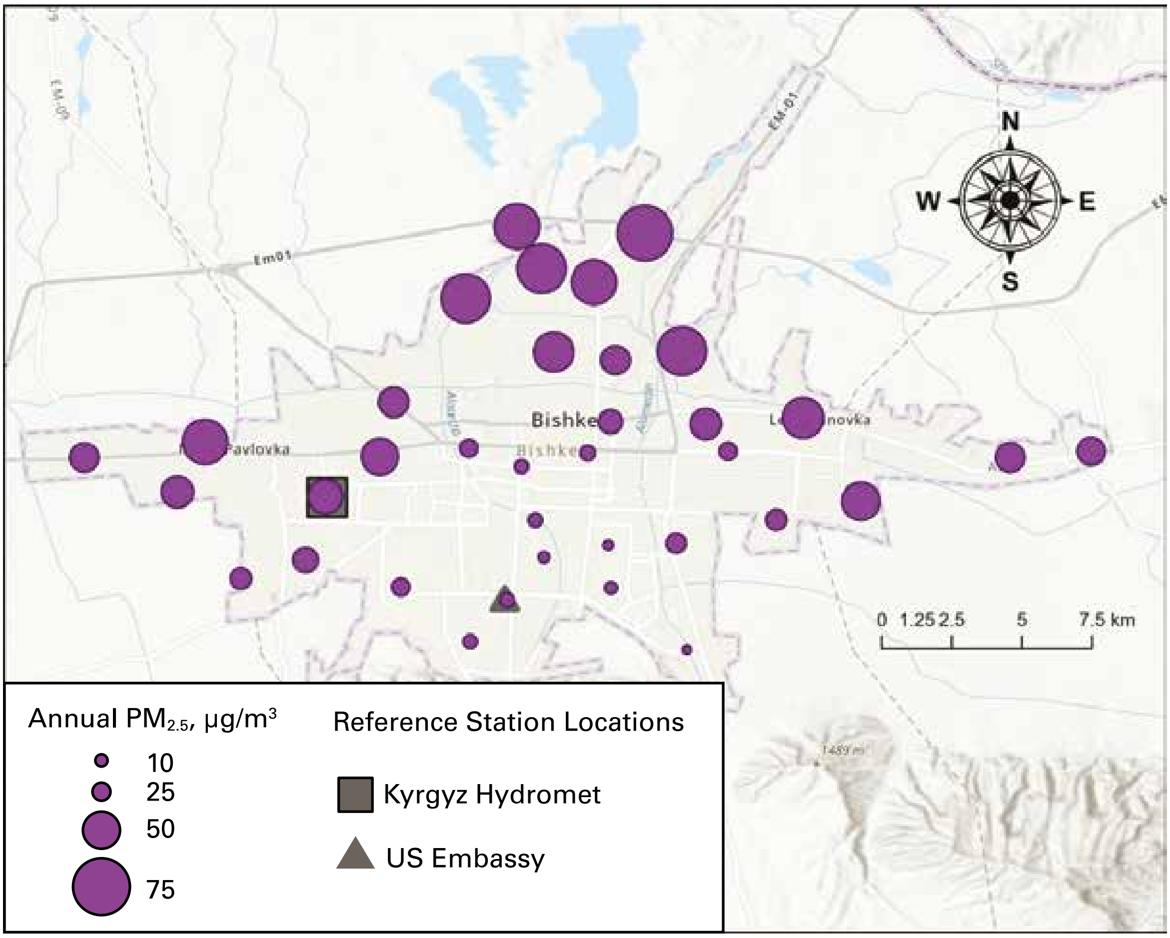


Figure 26. Annual average $PM_{2.5}$ concentrations (July 2021-June 2022) for the Kyrgyzhydromet/ADB Clarity sensor network, bias adjusted.

Figure 27 shows spatial interpolation of the bias adjusted Clarity network $PM_{2.5}$ annual average data to obtain the concentration surface for the city of Bishkek. This map further visually demonstrates the $PM_{2.5}$ spatial variability across the city with concentrations lowest in the south and highest in the north. The surface obtained by Kriging was used to estimate outdoor concentrations at each survey location and also spatially average concentrations in a 5 km radius buffer around each survey location (not shown). The latter estimates were used as to estimate workplace outdoor concentrations for individuals in houses that participated in the household survey. Superimposed on this map are columns that represent the fraction of houses in the household survey enumeration area using coal stoves. This map visually demonstrates the relationship between higher $PM_{2.5}$ concentrations and the neighborhood use of raw coal stoves for space heating.

Between 7/1/2021 and 6/30/2022, spatially weighted average annual $PM_{2.5}$ concentrations in Bishkek were 44 μg/m^{-3}, a factor 1.75 times higher than average annual $PM_{2.5}$ concentrations at the US Embassy of 25 μg/m^3 during the same time period due to location of the US Embassy monitoring site in the southern area of the city which has lower ambient $PM_{2.5}$ concentrations. While representing the urban area was not the primary purpose of the US Embassy monitoring site, the difference between the averages highlights the limitations of using a single central monitor to represent citywide air quality conditions to estimate health impacts, and also the importance of site location for fixed monitoring sites and sensor arrays as the Government of Kyrgyzstan expands its monitoring capacities in spatially representing the urban area.

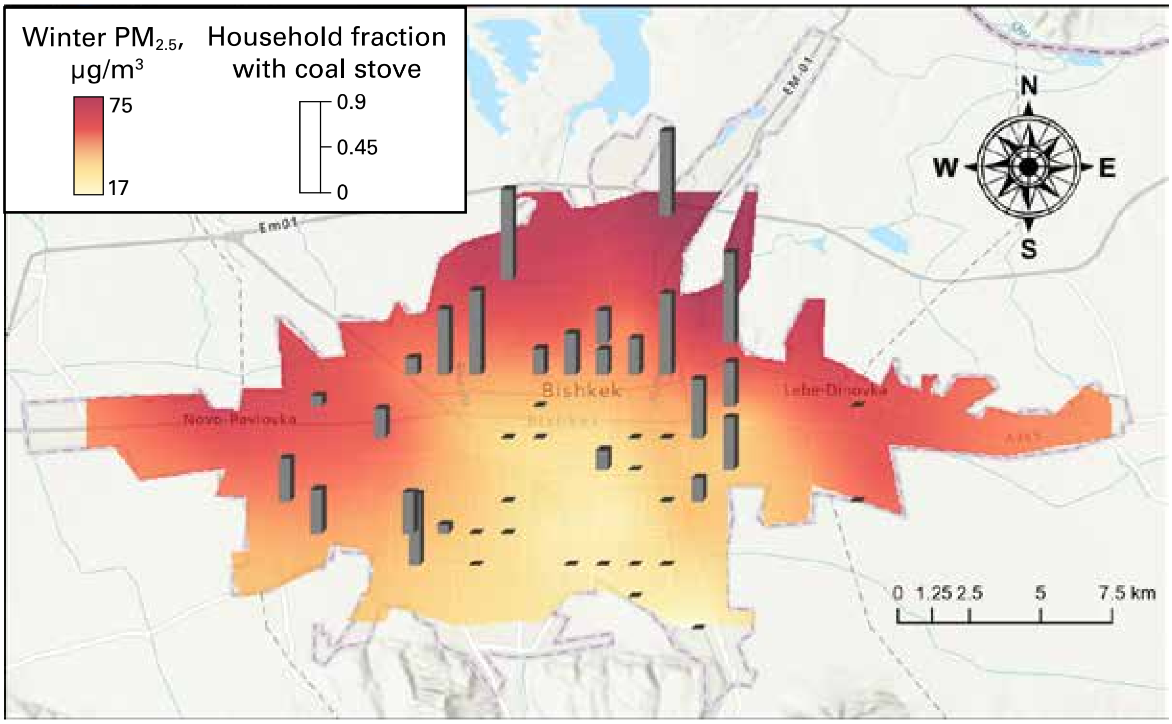


Figure 27. Contours: winter average $PM_{2.5}$ concentrations (November 2021-January 2022) for the Kyrgyzhydromet/ADB Clarity sensor network, bias adjusted. Columns: Fraction of households using raw coal stoves from the household survey. The two zones to the east with no stoves are apartment areas adjacent to neighborhoods with detached homes using raw coal stoves.

Figure 28 shows $PM_{2.5}$ diel (time-of-day) profiles for November 2021-January 2022 at four sites in the Kyrgyzhydromet/ADB Clarity sensor network. Mean values for each hour over the three-month period are displayed and have been bias adjusted using collocated Clarity and reference monitor data at the US Embassy location (Site A) in the southern part of the city. Site A exhibits a relatively flat diel profile throughout the morning with a gradually rise in the late afternoon and peak values at 1900-2000 hours. The influence of space heating in this profile is relatively low as the predominant wind direction for the city is from the south during wintertime. Site B is located in the central business district (CBD) and features a morning peak at 0900 hours, which is displaced a little later than similar peaks for sites C and D, which may coincide with morning rush hour, and a broad peak of ~100 μg/m^3 throughout the evening, which reflects space heating emissions. Diel profiles for sites C and D, located in residential areas, generally follow the CBD profile except the morning peak is earlier and the peaks much higher in concentration also indicating a significant impact from residential heating with coal in the morning. $PM_{2.5}$ wintertime mean concentrations overnight are above 150 and 200 µg/m^3 for sites C and D, respectively. The data illustrate the different ranges of concentrations experienced by residents in different areas of Bishkek during the winter.

In the mid-afternoon, $PM_{2.5}$ concentrations are nearly identical across the four sites and are the least polluted time of day for three of these sites. An analysis of all sites in the Kyrgyzhydromet/ADB Clarity network (not shown) confirmed this pattern is consistent across the city. While some regions of the city might be modestly less polluted in the morning, on the city scale afternoons are the preferred time for outdoor activities.

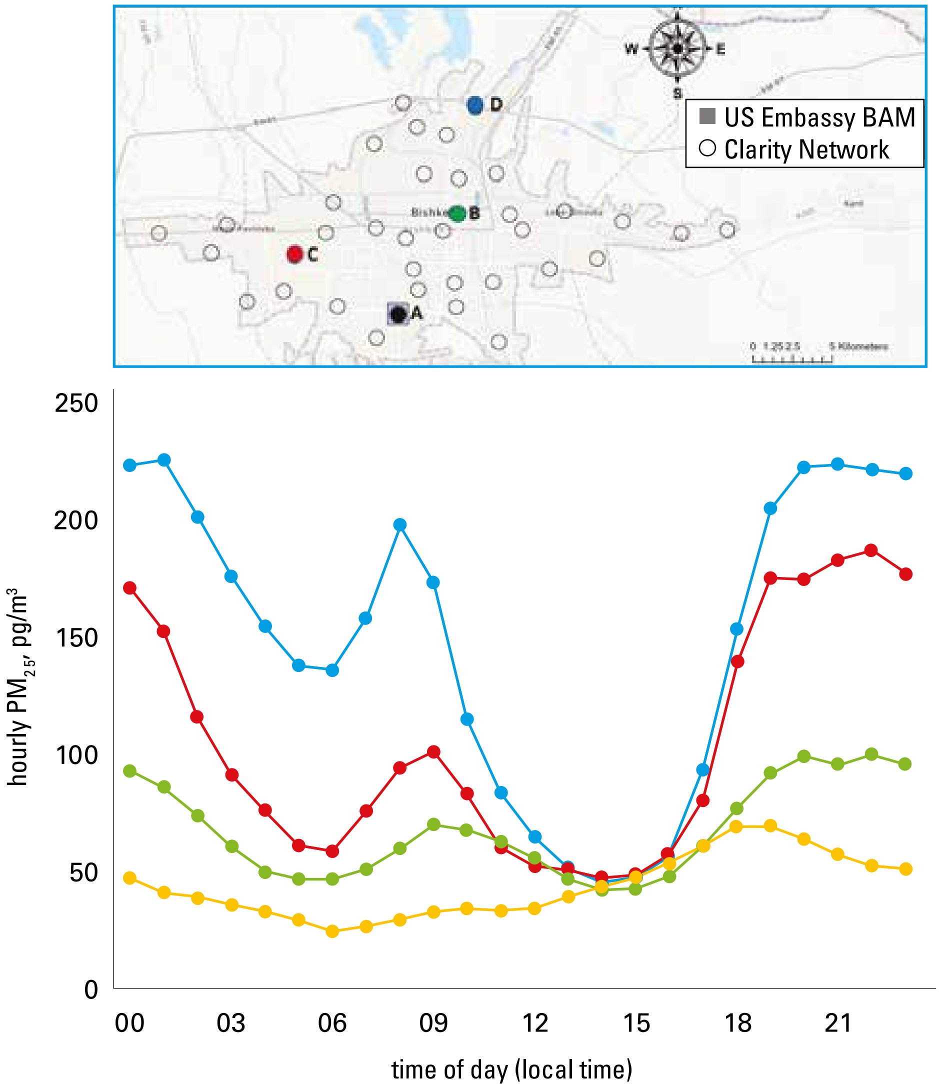


Figure 28. $PM_{2.5}$ diel profiles for November 2021-January 2022. The map shows the monitoring locations (A-D).

Historical ambient concentrations

Gupta et al. (2022)25 used NASA's Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA2) reanalysis data of aerosols and meteorology in a machine learning algorithm to estimate long-term trends in $PM_{2.5}$ at select US Embassies. Figure 29 shows preliminary results for the US Embassy Bishkek location. Annual averages range from 29 to 39 μg/m³ with a non-significant annual rate of change over the 21-year period, possibly as a result of the location of the US embassy in the lower concentration southern part of the city. The data, however, suggest that $PM_{2.5}$ air pollution has been a persistent problem for Bishkek which was underrecognized due to the limited amount of available environmental monitoring. There is more interannual variability in the most recent ten years (σ = 3.4 μg/m³) compared to the first ten years (σ = 1.5 μg/m³).

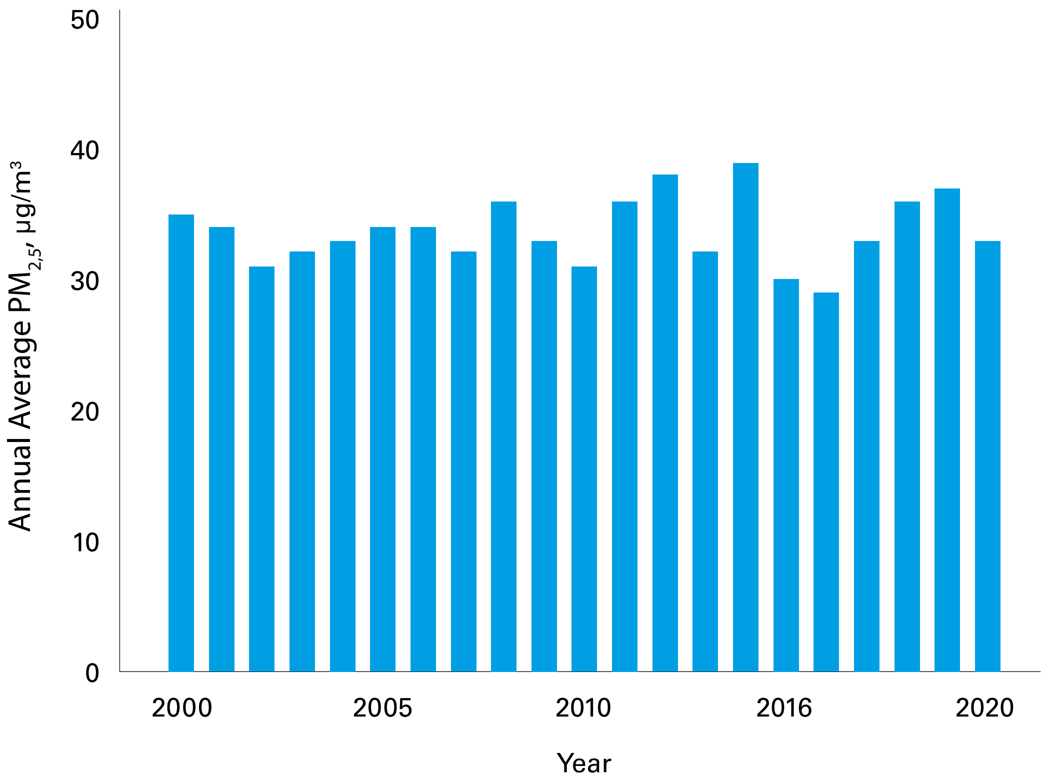


Figure 29. Annual average $PM_{2.5}$ for the US Embassy Bishkek location (Gupta et al., 2022). For 2020, the modeled estimate is 33 μg/m³ for all days and 30 μg/m³ after removing days with invalid monitoring data (σ); in good agreement with monitoring data annual average of 28 μg/m³ (σ).

3.5. EXPOSURES TO $PM_{2.5}$

Table 7. Smoking prevalence inside the home

	Does anybody smoke inside the house?		
	%	%	%
	Yes	No	Total
Households Total, n=1007	7.9%	92.1%	100.0%

Table 7 shows a relatively low frequency of smoking inside homes reported by participants in the household survey.

Time activity

The household survey collected information on 373 Adults >65, 2188 adults >18 and <65, 595 Adolescents >10 and <18 and 928 children ≤10, with a total of 4084 individuals. To estimate time spent in outdoor, work indoor and home indoor environments, time activity information was obtained from the 2021 Time Budget Survey of the National Statistical Committee of the Kyrgyz Republic[xxxix]. Time activity estimates were also informed by employment data for Bishkek from the National Statistical Committee of the Kyrgyz Republic combined with age fractions of children under 10 and attendance rates in nursery schools, kindergartens and schools. For exposure estimation, age fractions of children not attending nursery school or kindergarten were distributed evenly to each household that reported Children under 10 years old in the family, and exposures were not distinguished by gender. Time spent in nursery schools and kindergartens was weighted by attendance rates and distributed evenly across households with children in the survey sample. Since maternity leave is 1-2 years funded by state or company when child is born, with the potential for an additional year of unpaid leave, children under 2 were assumed to be under the care of an adult "caretaker" at home during this period. For young children in winter the average day for children and caretakers would be spent approximately 100% indoors. In Bishkek participation in early child education in kindergarten between 3-5 years is 60.6% between the hours 8am-5pm, and for children 6 years old before school 78.7% between the hours 8am-5pm. Children in school have a greater than 97% participation and were assumed to be at school during the workweek.

Time spent by adult residents in outdoor, work indoor and home indoor environments likely differs by socio-demographics, occupation and season. The most significant factors for differences in time activity information in European cities, with similar contributions in all cities, were the specific work status, employment status, whether the participants were living alone, and whether the participants had children at home[26]. The factors associate with different time activity patters also lead to different exposures to $PM_{2.5}$[27] and volatile organic compounds[28]. While time budget data for Bishkek is available for employment status and those with children and those without children, in practice the time spent in outdoor, work indoor and home indoor environments were similar between those with children and no children under the assumptions made (overall sample 7%,70% and 23%; 7%, 70% ,23% with children and 7%, 75% and 18% with no children for outdoor, home indoor and work indoor respectively), time activity estimates were therefore based on the overall sample population for both men and women combined. Gender and season were associated with time activity in European cities with effects mixed across locations, however in general men spend less time at home indoors[26]. Gender also has a significant impact on time activity in Bishkek. For men percentage of time in outdoor, work indoor and home indoor was 8%, 65% and 27% while in

xxxix http://www.stat.kg/en/publications/obsledovaniya-byudzheta-vremeni/

women it was 6%, 74% and 19% respectively because women spend more time at home and less outdoors and in work. Overall the fractions of time spend indoors and outdoors closely reflect those in the United kingdom[29], and the US. Similar time was spent outdoors or in transit in Los Angeles 10.6%, Elizabeth 8.1%, and Houston 7.9%, respectively, as part of the RIOPA Study[30].

Employment rates for adults 18-65 years old were 72.5% for males and 54.6% for females with a combined 62.7% of the population in 2020. The time activity estimates however incorporate proportion of working population into the overall time budgets for the adult population in Bishkek. The free time category in time budget surveys in Bishkek allocated to time spend in different environments. Sports, recreation and moving between environments were assumed to be in environments with air pollution concentrations equivalent to outdoors, socializing was assumed to be visiting in other indoor environments, and watching TV listening to radio, reading and hobbies were assumed to be indoors at home. As a result 15% of free time was outdoors, 70% was indoors and 15% was in other indoor environments. Adults over 65 years old were assumed to no longer work and spend additional time home indoors during the winter as a result.

Exposure estimation

Since the household survey was a stratified random sample, average household $PM_{2.5}$ exposure concentrations were estimated for each household member in the household survey, (n=4084 individuals in 1007 households). Exposures were summed for the fraction of the year for 3 time periods (s): winter, summer and transition periods during fall and spring where temperature do not require continuous heating requirements. Exposures are estimated from indoor (in) and outdoor (out) concentrations (C) during the day (D) (8:00 to 17:00) and during at night (N) (17:01 to 07:59) weighted by the number of hours (t) during a typical 24-hour period spent in workplaces (wi), home indoors (Hi), other indoor (Oi), and outdoor environments during the specified time period (Eq 1).

$$\sum_{s=1}^{s=n}\left(\lambda_s\left(\frac{(t_{Hi,D,s} . C_{Hi,D,s}) + (t_{Wi,D,s} . C_{Wi,D,s}) + (t_{Oi,D,s} . C_{Oi,D,s}) + (t_{out,D} \ . C_{out,D,s})}{}\right)\right)$$

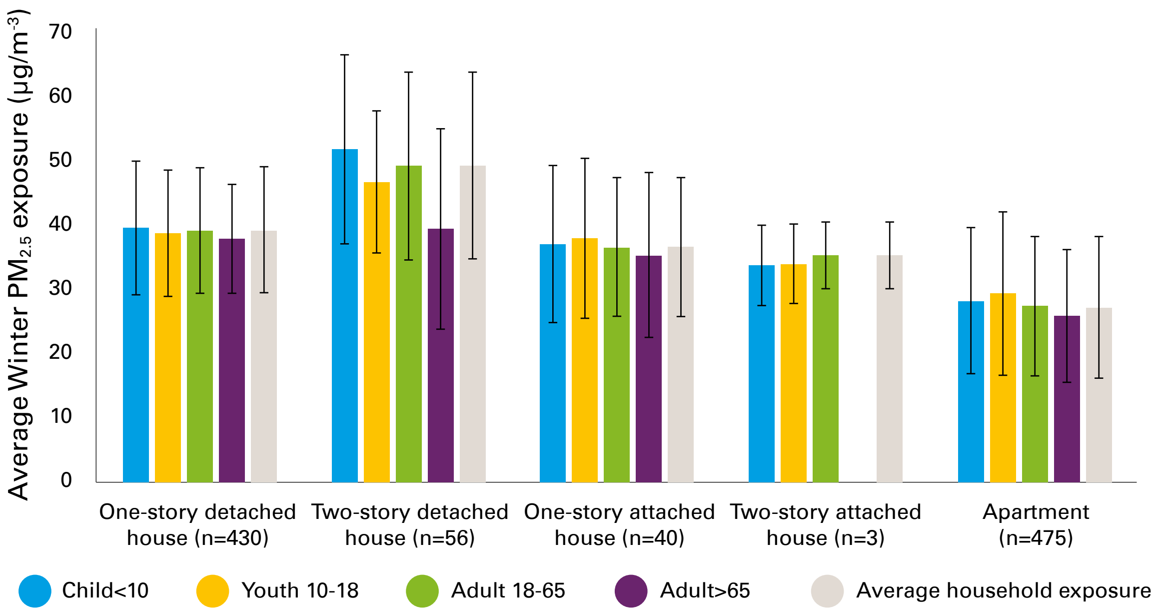
Citywide population-weighted average exposures were calculated by aggregating the exposure concentrations for all individuals living in the surveyed homes. Indoor and outdoor concentrations for each home were estimated for each house in the household survey based on ambient concentrations outside the home and measured indoor vs. outdoor concentration ratios (I/O) measured as part of this study (Table 8). A one-way ANOVA test yielded no statistically significant differences across the four categories ($p = 0.48$) and thus the average of 0.5 for all data was used in exposure estimates.

Table 8 Indoor and outdoor $PM_{2.5}$ concentration ratios (I/O) for different heating arrangements.

	stove with pipes	stove without pipes	central heating	pipeline gas	ALL DATA
Count	8	30	6	4	48
Mean	0.47	0.55	0.42	0.55	0.52
St. Dev.	0.17	0.23	0.11	0.37	0.22

Figure 24 shows average household $PM_{2.5}$ exposures by housing type during a) winter and b) summer, and Figure 25 shows average annual exposures by house type. In general there are significant differences in estimated exposures ($P<0.0001$) between housing type, driven largely by the higher exposures in one-story detached family homes compared to apartments. Since stoves are vented through chimneys to the outdoor environment, exposures reflect the infiltration of emissions from elevated neighborhood concentrations into indoor spaces, which is a function of the number of chimneys emitting in the near vicinity of the house. The whisker lines on the graphs reflect the locations of the individual housing types in different neighborhoods across the city sampled as part of the household survey (Figure 24). As a result, the differences in exposures observed within and between housing types is dominated by the high spatial variability in neighborhood concentrations.

a) Winter



b) Summer

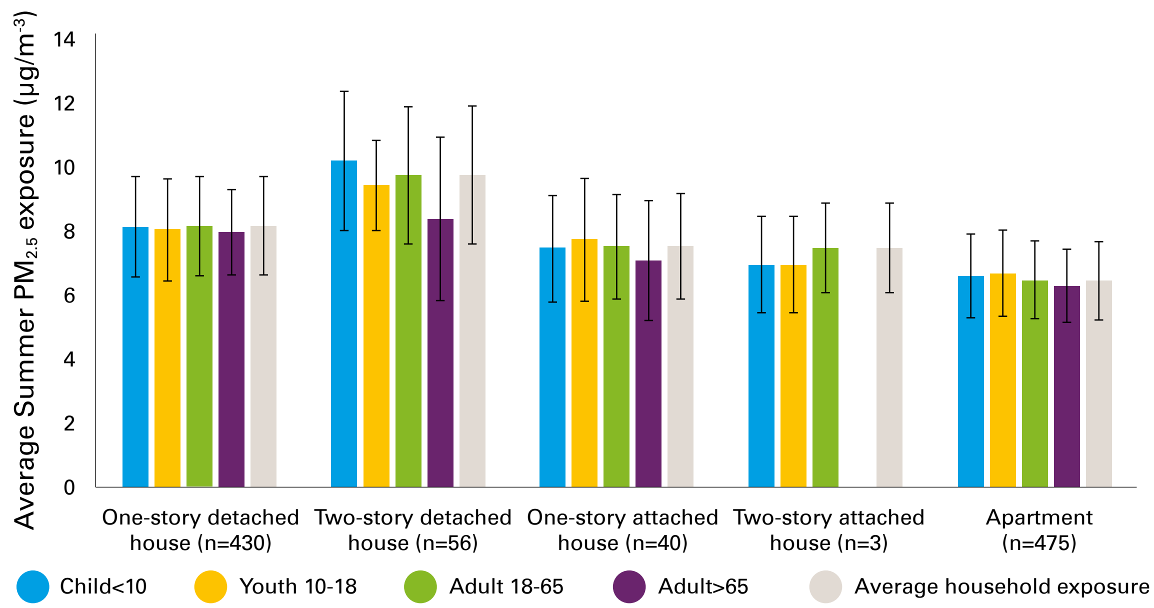


Figure 24. Average household $PM_{2.5}$ exposures by housing type

Figure 25 shows average annual household $PM_{2.5}$ exposures by housing type. Whisker bars represent the range of exposures estimated over the spatial area of Bishkek.

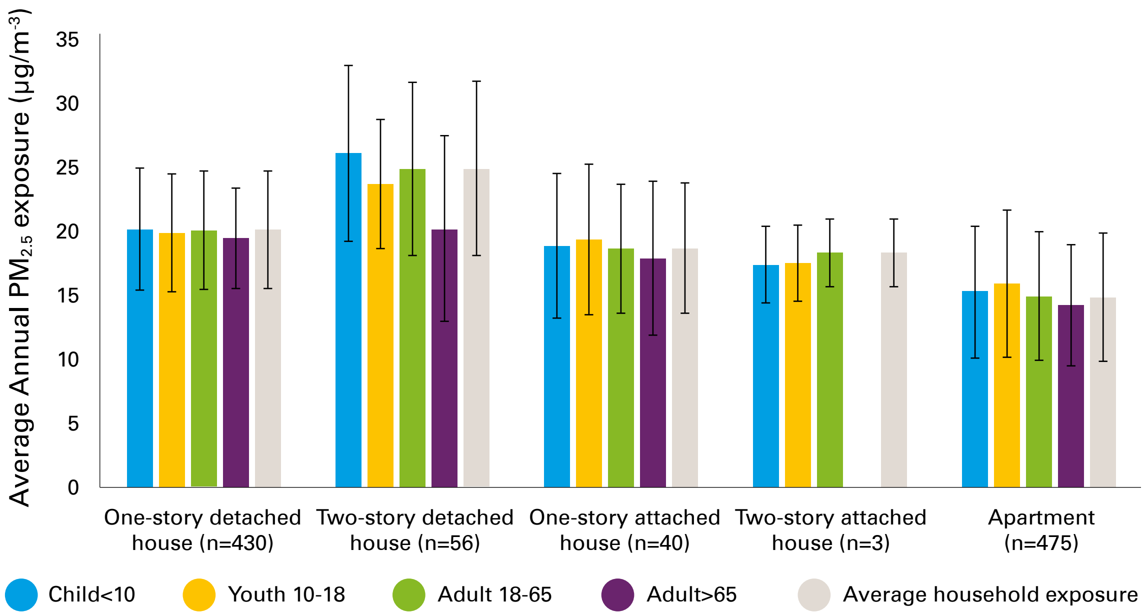


Figure 25. Average annual household $PM_{2.5}$ exposures by housing type

Figure 26 shows average household $PM_{2.5}$ exposures by central heating or other type of heating that demonstrates that apartments with central heating have significantly lower exposures ($P<0.0001$) during the Winter, which decrease during transition months and summer as space heating is reduced. Here again the whisker bars represent the variability in concentration across the city.

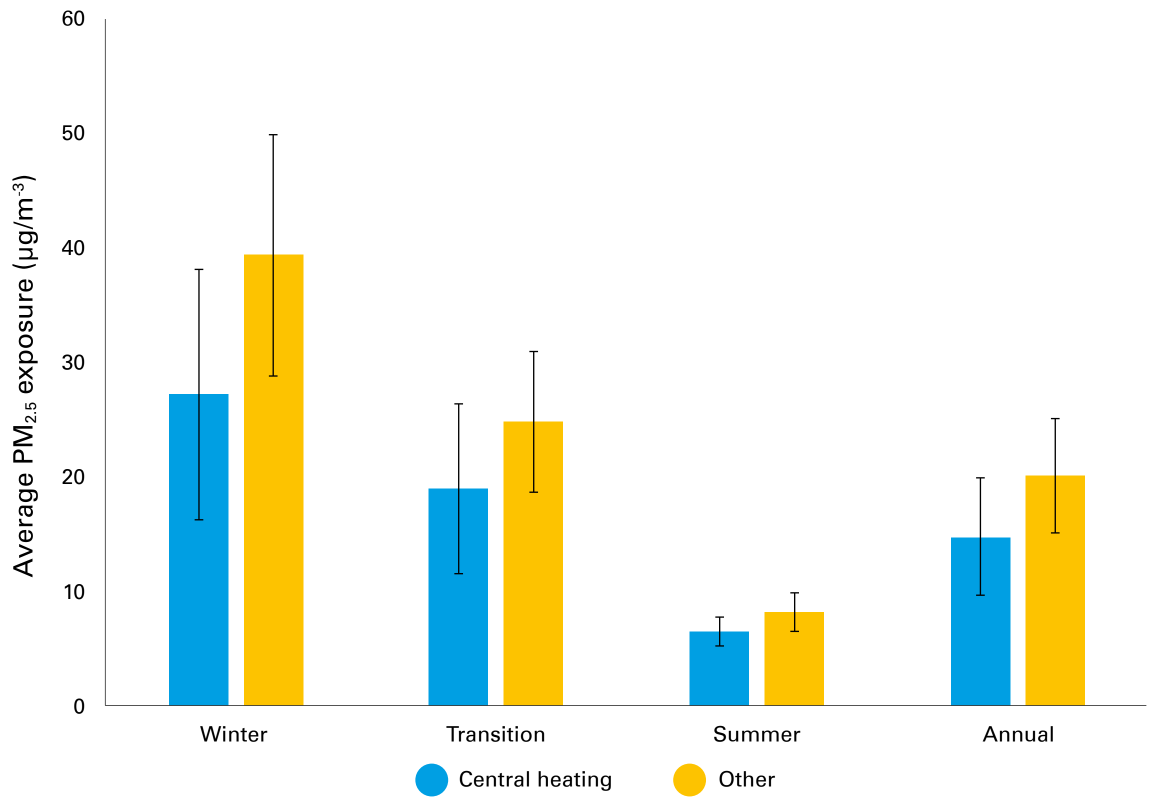


Figure 26. Average seasonal household $PM_{2.5}$ exposures by central heating or other heating type

Similarly, Figure 27 shows average household $PM_{2.5}$ exposures by primary winter heating type. In general exposures for individuals increases as you move from district co-generation central heating to natural gas central heating and natural gas heating with radiators reflecting the increasing distance from the urban center. Subsequently there are increasing exposures for those with electric heating and the highest exposures for households using raw coal in stoves as homes are increasingly in neighborhoods with higher neighborhood concentrations from increased burning of raw coal. The impact of winter heating on exposures is evident across all heating types with wintertime concentration significantly elevated of transition periods, and both much higher than in summer. In summer air pollution exposures are close to WHO air quality guidelines with an average household exposure of 7.3 ± 1.7 μg/m^{-3}. These patterns reinforce that high air pollution exposures in Bishkek are driven by local winter heating, and the greatest increase in exposures is for those living in areas where raw coal burning is more evident. These patterns also reinforce that measures to reduce air pollution across the city would therefore benefit all residents.

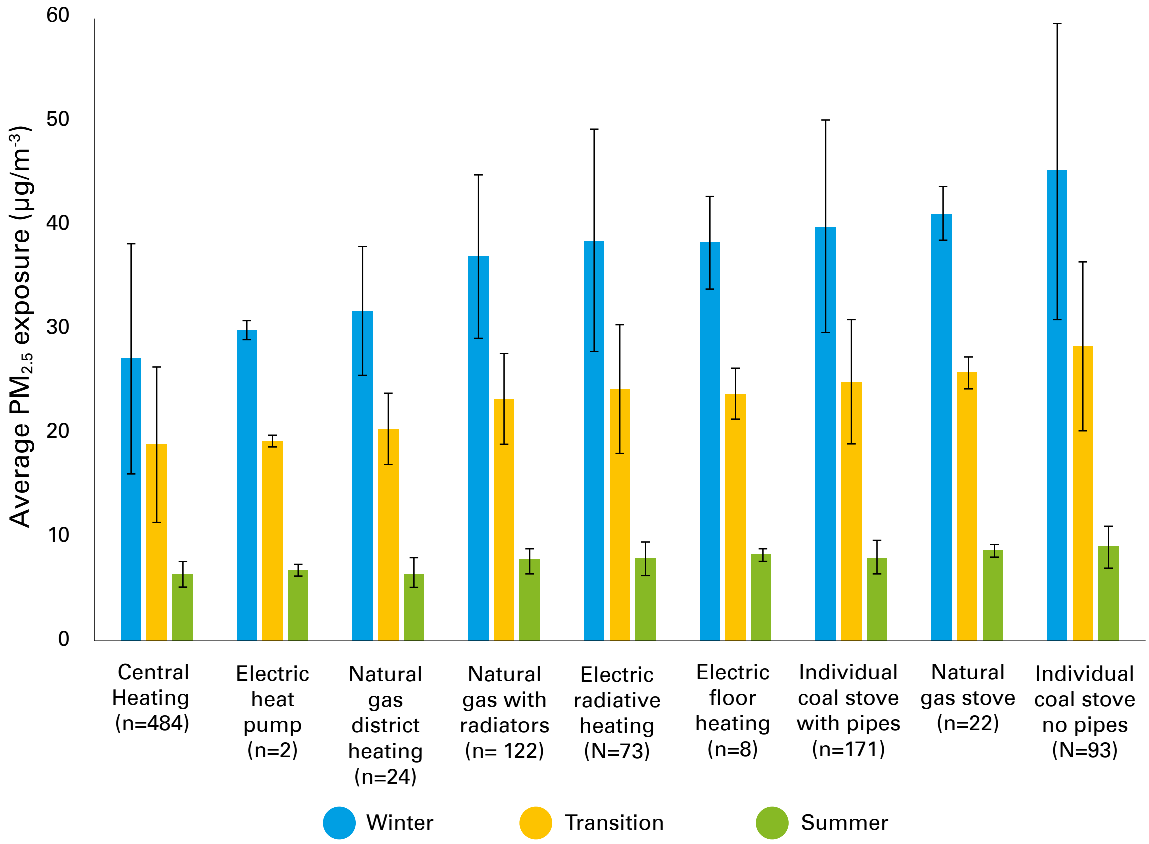


Figure 27 Average household $PM_{2.5}$ exposures by primary winter heating type.

Figure 28 shows average household $PM_{2.5}$ exposures by reported monthly household income. In general wintertime exposures for individuals decrease as you move from less affluent to more affluent populations, and there are significant differences in exposure ($p<0.001$) between the least affluent and most affluent groups with average wintertime exposures of 38.8 and 29.3 μg/m^{-3}, or on average 9.5 μg/m^{-3} difference in exposures between these groups. The decrease in exposures for incomes between 5-10,000 Som per month is explained by the older average age in this category (Figure 29), where a higher percentage live in apartments (53.5%) compared to the adjacent categories (<5000 SOM – 35.9%; and 10,000-15,000 Som – 38.9%). Since those living in apartments with central heating have lower exposures, the average exposures for this income category are lower.

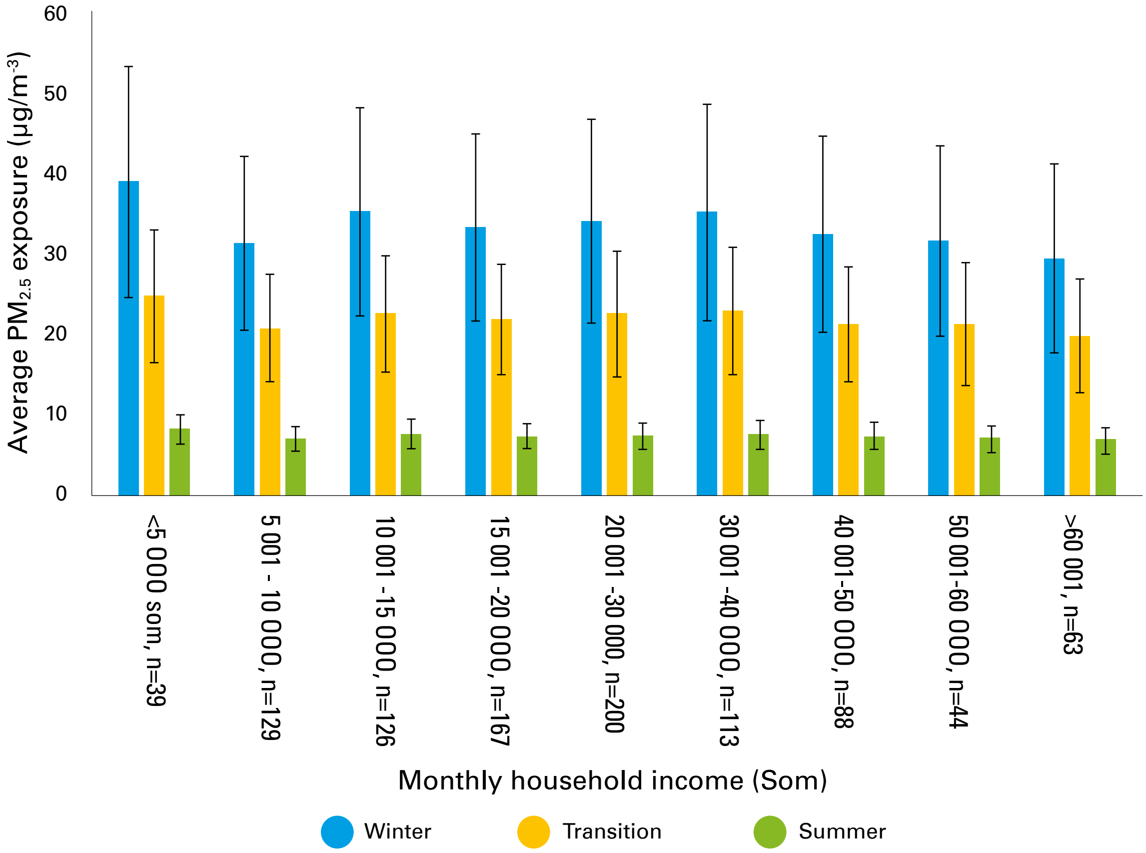


Figure 28 Average household $PM_{2.5}$ exposures by monthly household income.

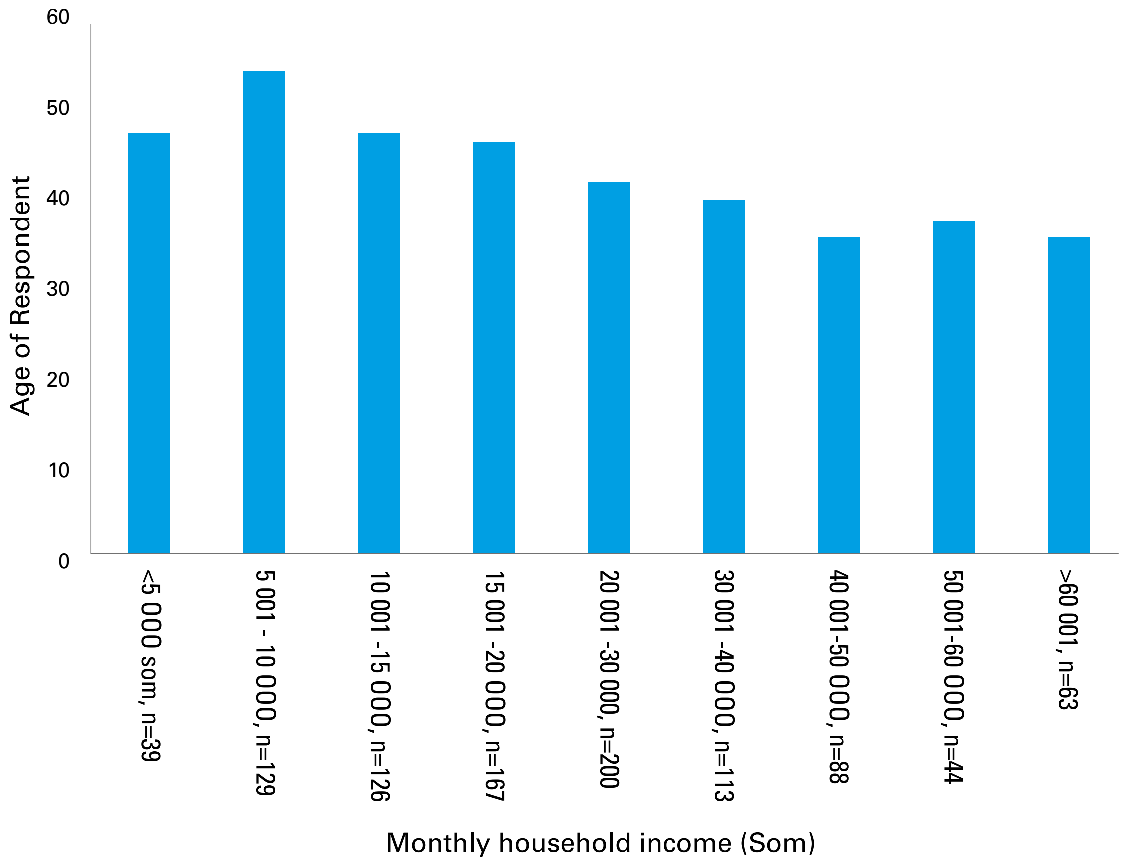


Figure 28 Average age of respondent by monthly household income

Population weighted annual average exposures for the household survey representative sample were 18.0 μg/m^{-3}, with annual average population weighted exposures for children under 10 years old 18.5 μg/m^{-3}, and for adults 17.7 μg/m^{-3}.

3.6. HEALTH IMPACTS OF AIR POLLUTION IN BISHKEK

Exposure to ambient air pollution increases mortality and morbidity and shortens life expectancy[31]. The primary indicators of health effects for combustion-related pollution are $PM_{2.5}$, particles with a median aerodynamic diameter smaller than 2.5 μm that can penetrate deep into the lung, and to a lesser extent tropospheric ozone. More information on $PM_{2.5}$ related health effects exists than for any other pollutant, although it is recognized that for some diseases it may be an indicator of combustion pollution in general and that other pollutants may play roles in health effects.

Relationships of particulate matter with health effects are well established internationally. Although a large proportion of this evidence is from more developed settings, short-term exposures to $PM_{2.5}$ air pollution indicate similar responses in Indian[32] populations, and long term exposures in Chinese[33] populations, with those in other countries. While prospective cohort studies for studying the long-term health impacts of air pollution in each location may provide more refined city specific estimates, and more recent studies in high income countries conducted at a smaller geographic scale, have reported substantially larger effects[34], which has important implications for estimates of years of life lost in urban areas[35], the available evidence indicates that the relative risks associated with exposure to air pollution from studies worldwide can be used to estimate health impacts in populations in less developed settings[36]. In practice the costs and time involved in conducting additional cohort studies to establish dose response relationships gives them limited utility is addressing the high air pollution situations in Bishkek, particularly in environments where resources are limited and there are many other competing information needs.

Given the difficulties in obtaining robust estimates of disease incidence, use of Global Burden of Disease[2] approaches was a pragmatic choice for estimating the impacts of $PM_{2.5}$ on health outcomes in Bishkek. The health impact estimates are not intended to be predictors of disease in individuals, rather they are intended as an objective assessment of health impacts on a population basis, which can be used to evaluate policy options. These assessments do not take the place of the national and global work that is required to map disease incidence, on which these estimates are based. Global Burden of Disease estimates are based on causal relationships of $PM_{2.5}$ with ischaemic heart disease (IHD), cerebrovascular disease (ischaemic stroke and haemorrhagic stroke), lung cancer, lower respiratory infections (LRI), chronic obstructive pulmonary disease (COPD), type 2 diabetes and low birth weight (LBW) for which non-linear exposure-response functions exist spanning the global range of exposure[37]. In addition, the impact of air pollution on cataract formation is included in morbidity from air pollution. Global Burden of Disease estimates limit analyses to environmental risk factor-disease pairs for which there is definitive evidence of causality, which underestimate the full impacts as there is evidence for causal associations of diseases and risk factors not yet included in the GBD study[38]. In addition more recent research has indicated long-term exposure to concentrations of $PM_{2.5}$ and NO_2 lower than current annual limit values was associated with non-accidental, cardiovascular, non-malignant respiratory, and lung cancer mortality in seven large European cohorts[39], resulting in a lowering of counterfactual concentrations where health impacts are thought not to occur, and thus an overall increase in impacts that was offset by more refined exposure extimates[36].

In this study health impacts of $PM_{2.5}$ air pollution were estimated using Air Burden of Disease Explorer (ABODE)[xl], which is based around the integrated exposure response curves used in Global Burden of Disease estimates which relate exposure to $PM_{2.5}$ with the population attributable fraction of disease risk[2]. Table 9 shows population weighted exposures and average life expectancy for health estimates. ABODE estimates ill-health averted due to changes in $PM_{2.5}$ exposure levels in terms of morbidity (DALYs) and mortality for 6 health outcomes – chronic obstructive pulmonary disease, lung cancer, stroke, ischemic heart disease, lower respiratory infection, and type 2 diabetes. Separate curves exist for each endpoint and for different age groups. Low birth weight is not currently included due to the complexity of the exposure response functions.

Table 9 Population weighted exposures and average life expectancy for health estimates

	Mean (µg/m^{-3})	95% Confidence Interval	
		lower bound	Upper bound
Population weighted mean annual exposure	18.0	17.6	18.4
Population weighted mean annual exposure children <10	18.5	18.0	19.0
Population weighted mean annual exposure adults	17.7	17.3	18.1
Average life expectancy from birth total	71.9		
Average life expectancy from birth - males	67.8		
Average life expectancy from birth - females	76.0		

The counterfactual exposure refers to the lowest exposure concentration used in comparison with the population-weighted annual mean exposure to estimate health impacts. Health impacts below this cut-off are excluded because the shape of the exposure response curve below observed values is not known, and these concentrations are not of practical policy significance. Health estimates as part of the current study use a counterfactual population weighted annual average exposure of 5 µg/m^{-3}, as this is close to estimated summertime exposure concentrations in Bishkek, is the counterfactual level used in the current version of the comparative risk assessment, and aligns with the recently revised annual WHO guideline value for $PM_{2.5}$ exposure.

Since baseline frequencies of health impacts were not readily available for Bishkek city and surrounding areas, particularly as there are significant underreporting biases possible for informal areas surrounding the city, health impact incidence rates for the population of Kyrgyzstan were scaled to the approximately ~16% of the population that live in Bishkek to estimate disease burdens for the city. Table 10 show disease burdens attributable to population weighted $PM_{2.5}$ exposures to air pollution in Bishkek during 2021 for a) DALYs and b) Deaths. In 2021 $PM_{2.5}$ air pollution concentrations were estimated to cause 112 deaths and the loss of 3568 disability adjusted life years in Bishkek. Ischemic heart disease was estimated to cause 53% of the deaths, followed by Stroke and COPD. Ischemic heart disease was estimated to cause 35% of the DALYs, followed by lower respiratory infections in children, and stroke. Although Kyrgyzstan has recently introduced PCV13 vaccination, DALYs due to acute lower respiratory infections account for 22% of disease burdens attributable to $PM_{2.5}$ air pollution exposures in 2021 and efforts to reduce exposures during pregnancy and in the first year of life should be a high priority.

xl Air Pollution Burden of Disease Explorer. Berkeley, CA: UC Berkeley. 2013-2021. Available from http://householdenergy.shinyapps.io/abode. (Accessed September 2022).

Table 10 Disease burdens attributable to population weighted $PM_{2.5}$ exposures to air pollution in Bishkek for a) DALYs and b) Deaths

DALYs

Health endpoint	DALYs	95% Confidence Interval		Age Group	Fraction of disease burden
		Lower Bound	Upper Bound		
COPD	433	362	512	> 15 years	12%
IHD	1251	1121	1395	> 15 years	35%
Lung Cancer	144	114	181	> 15 years	4%
LRI	163	117	227	> 15 years	5%
Stroke	513	443	590	215 years	14%
Diabetes	277	192	386	2 15 years	8%
LRI	787	641	929	Under 5 years	22%
TOTAL	**3568**	**2990**	**4220**	**All ages**	

Deaths

Health endpoint	DALYs	95% Confidence Interval		Age Group	Fraction of disease burden
		Lower Bound	Upper Bound		
COPD	15	13	19	> 15 years	13%
IHD	59	53	63	> 15 years	53%
Lung Cancer	5	4	7	> 15 years	4%
LRI	5	3	8	> 15 years	4%
Stroke	18	16	21	215 years	16%
Diabetes	1	1	2	2 15 years	1%
LRI	9	7	11	Under 5 years	8%
TOTAL	**112**	**97**	**131**	**All ages**	

3.7. ECONOMIC IMPACTS OF AIR POLLUTION IN BISHKEK

In general, pollution is costly for individuals, families, and society. Pollution-related diseases cause productivity losses that reduce GDP in low-income to middle-income countries by up to two per cent per year[5]. Pollution-related diseases also result in health-care costs. They are responsible for 1.7% of annual health spending in high-income countries and for up to 7% of health spending in middle-income countries that are heavily polluted and rapidly developing, with welfare losses estimated at 6.2% of global economic output[5]. Standard methods have been used to estimate the economic cost to society[xli] of mortality from air pollution, which is by far the largest component of the cost of air pollution[22]. Analyses of the benefits of the U.S. Clean Air Act in the period 1990-2020 included averting 230,000 deaths which comprised 92.4 per cent of economic benefits to society from reduction of health impacts, and about 88 per cent of total estimated benefits[12]. Premature deaths due to air pollution in 2013 cost the global economy about $225 billion in lost labor income, or about $5.11 trillion in welfare losses

xli Sometimes referred to as social cost, welfare cost, welfare loss, or loss in social welfare.

worldwide[xlii]. Similarly, ambient air pollution in the 35 member-countries of the OECD and the six major emerging economies (Brazil, Russia, India, Indonesia, China and South Africa) increased over the fifteen-year period from 2000 to 2015 resulting in around 3.2 million deaths at the cost of about USD 5.1 trillion in 2015[22].

There are a number of approaches for estimating an individual's willingness to pay for air pollution reductions and the associated aggregated value of a statistical life. These can be loosely grouped under stated preference and revealed preference, where the stated preference relies on a direct open bounded question on willingness to pay, and revealed preference uses market-based data on population purchase patterns or wages in related areas to infer a willingness to pay based on actual trade-offs individuals make involving risks. The limitations arise in that the revealed preference may not be relevant to the area that the estimate is applied to. Stated preference studies elicit estimates of the affected population's willingness to pay for a mortality risk reduction through a variety of survey techniques, including phone surveys, web-based surveys, mail surveys, and in person surveys. Contingent valuation surveys (CVS) ask people to report information about their willingness to pay (WTP) for a specified- and finite-reduction in their risk of dying using a randomized bid structure. Frequently the questions about willingness to pay involve 2 successive contingent bid questions, where the answer to the first bid is followed by a successive higher bid if Yes or lower bid if No. CVS lend themselves to valuing risk reductions in many contexts and circumvent many of the shortcomings of other VSL estimation approaches. VSL equals the sum of the marginal value of the fatality risk and the marginal value of the morbidity risk.

To estimate the Willingness to Pay (WTP), Value of a Life Year (VOLY), and welfare losses in Bishkek a contingent valuation survey was administered to 600 residents of Bishkek as a subsample of the 1007 home household survey. A contingent valuation survey consists of a hypothetical scenario where a randomly selected household member is presented with a scenario where the individual can perform certain activities at a cost that will result in a marginal improvement in health outcomes extending their lifetime and the quality of those years, and asked whether they would be willing to pay predetermined amount of money for this extended amount of life. The amount of money for each individual is randomly selected from a predetermined bid structure. The Hypothetical scenario and the bid structure are presented in Appendix 6. Briefly the marginal length of time added to the lifetime was 2 years, which approximately reflects the estimated increase in average life expectancy by reducing air pollution in 2017 to levels thought to have minimal risk in China (1.25 years[40]) and India (1.7 years, with this increase exceeding 2 years in the north Indian states of Rajasthan, Uttar Pradesh, and Haryana[36]); and 5 years, which reflect actual estimates of improvements in life expectancy (5 yrs) resulting from reduced air pollution exposure to coal emissions of approximately 184 $\mu g/m^{-3}$ as a result of the Chinese Kuai river policy[41], or a 10- $\mu g/m^{-3}$ increase in PM10 reducing life expectancy by 0.64 years[42]. Similar estimates for an increase of 10 $\mu g/m^{-3}$ $PM_{2.5}$ in ambient air in the US were 0.6-1.01 years[43]. Since spatially weighted average annual $PM_{2.5}$ concentrations in Bishkek between7/1/2021 and 6/30/2022 were 44 $\mu g/m^{-3}$ this would translate to approximately 2.3-3.9 years, which is similar in range to the marginal length of time added to the lifetime.

The range of WTP in Western industrialized nations, Mexico[18], and in China[20] have been reported between 0.81-3.5% of income for a risk reduction of 5 in 1000. In addition a similarly structured contingent valuation study in Turkey based bid structures on 1.5% of annual income and went up to 5%,7% and 15% of annual income for different areas with increasing income[44]. Bid estimates for Bishkek were estimated for each quintile of monthly household income and ranged between 0.8 to 5% of monthly income within each quintile, with an upper bound of 8% for the lowest quintile. The contingent valuation relied on a 2-tier question approach (i.e. if the first bid was accepted a higher bid was then asked (bid high), if rejected a lower bid

xlii https://openknowledge.worldbank.org/handle/10986/25013 was asked (bid low). Bid structures for bid high and bid low remained consistent within and between income quintiles as a fraction of income (0.7-0.8) while preserving only 2 significant numbers for ease of comprehension.

By recruiting a representative population sample of individuals of various ages, the elderly, and those with existing health conditions, we estimate the Value of a Life Year (VOLY) for the population of Bishkek and the resultant welfare loss (Table 11). Because the VSL is likely to vary with age due to the remaining amount of life expectancy and because economic resources vary with age as individual economic resources also have a strong age relationship, here we compute the VOLY.

Table 11 WTP for health lifestyle choices and household improvements to reduce air pollution, VOLY and estimated welfare loss from $PM_{2.5}$ air pollution in Bishkek in 2021-2022.

	2 year extension (KGS)		2 year extension (USD)	
	Healthy life	House improvement	Healthy life	House improvement
Mean willingness to pay (WTP)	33.047	31,660	396.564	379.92
Value of a Life Year (VOLY)	486,452	466,035	5837	5592
Estimated welfare loss	1.7 Billion (1.4-2.0)	1.6 Billion (1.4- 2.0)	20.8 Million (17.5-24.6)	20.0 Million (16.7-23.6)

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

OPPORTUNITIES FOR REDUCING AIR POLLUTION

4. OPPORTUNITIES FOR REDUCING AIR POLLUTION

The 2030 Agenda for Sustainable Development adopted at the United Nations Summit on Sustainable Development in September 2015 includes:

- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
- Goal 3.9 by 2030 substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination

Meeting these goals in Bishkek will require sustained and coordinated action to change the primary energy use for 26% of the urban population. With increasing awareness there are days that air pollutions concentrations in Bishkek are reported to top the list of the world's most polluted cities, and growing interest of the multilateral and bilateral agencies to address the problem, there is a need for coordination of actions through the inter-ministerial committee for programmatic consistency and cost effective use of time and resources. A long term strategic urban plan of what primary energy choices in Bishkek will look like over the next 20 years will aid in this endeavor. The inter-ministerial committee should be well informed of the economic burdens of air pollution, and the benefits of investing in intervention strategies quickly rather than more gradually, as these play a significant role in the choice of strategic approach and the associated cost. In addition, as with many urban areas, fuel choices on the periphery of the urban area play a large role in air pollution concentrations experienced in central districts. As a consequence, measures to reduce air pollution should extend beyond municipal boundaries, and the political and institutional mandates reflecting the larger urban airshed developed. For example, the South Coast Air Quality Management District[xliii] is the regulatory agency responsible for controlling air pollution emissions covering 6,729 square miles of Los Angeles, Orange, Riverside and San Bernardino counties, including the Coachella Valley, which is home to more than 17 million people–about half the population of the state of California.

In addition to residential heating, other source sectors play a role in air pollution in Bishkek that are currently difficult to quantify. Assessment of the contributions of facility level heat boilers and industrial emissions remains important in understanding emission contributions as these sources are difficult to separate using source apportionment methods when coal types consumed are very similar to those used by residential households. Traffic emissions and electrification of vehicles has received attention under the Clean Air bill[xliv], however these initiatives do not address the principal cause of poor air quality in Bishkek, the burning of raw coal in simple stoves and boilers, and thus remains only a preliminary step in delivering clean and healthy environments for Bishkek. The policy highlights, however, the need for reliable and accessible data to develop data driven policies based on cost effective reduction of health impacts. Emissions data, meteorological and environmental data collected using taxpayer funds should be openly accessible in a primary data format in addition to real time display on

xliii https://www.aqmd.gov/nav/about

xliv https://www.ndi.org/our-stories/combating-air-pollution-kyrgyzstan apps, as taxpayers have already paid to have access. Development of these data resources involves improvements not only in the quality of environmental assessment, but also in the quality of ehealth data accessible to researchers and government, and the institutional capacity and training in analysis and interpretation (Table 12).

Table 12: Integrated strategies to reduce air pollution-related disease

<table>
<tr><th colspan="2">STRATEGIC GOALS</th></tr>
<tr><td colspan="2">• Create a burn-free zones with no burning of coal and other solid fuels
• Increase building efficiency
• Expand geographic areas served by central heating through reducing transfer losses, retrofit of temperature controls on apartments, and energy consumption metering.
• Accelerate gas expansion to districts surrounding the urban center
• Increase accessibility to electricity in outlying urban areas
• Validate availability, affordability and acceptability of air-to-air heat pumps to replace residential coal stoves in homes not served by gas or district heating networks, a technology already present in Bishkek homes which has been demonstrated to be effective in colder climates.
• Monitor facility level heating boiler emission compliance with modern standards
• Monitor heavy industry compliance with modern standards
• Increase solar water heating where needed to expand grid capacity</td></tr>
<tr><td>Management</td><td>• Coordinate stakeholders through Inter-ministerial committee
• Convene biannual meeting to share information and coordinate action</td></tr>
<tr><td>Policy</td><td>• Outline an Air Quality Management District extending beyond municipal boundaries
• Formalize an urban master plan to map primary energy choices to different geographic areas of Bishkek to reduce air pollution to WHO air quality targets
• Prioritize policy based on cost effectiveness in reducing health impacts based on modelling and pilot trials</td></tr>
<tr><td>Evidence base</td><td>• Develop a robust emissions inventory to provide the foundation for effective air quality planning and management, including electricity generation, residential coal heating, heat only boilers, mobile sources, industry, waste management, and others.
• Given large differences in $PM_{2.5}$ concentrations in different city areas, expand $PM_{2.5}$ low-cost sensor networks to provide information for air quality planning and management and the support and logistics associated with data quality evaluation and maintenance.
• Where possible expand the multipollutant continuous ambient air monitoring (CAAM) network to provide high quality reference data for air quality planning and management through careful site selection.
• Improve health data quality with ultimate goal of point of care data entry
• Modernize sectoral standards for emissions
• Pilot interventions to demonstrate affordability and effectiveness
• Data sharing and accessibility</td></tr>
</table>

Institutional capacity	• Training of technical staff
	  • Epidemiologists in MOH
	  • Technical staff in Hydromet
	  • Emissions monitoring
	  • Teacher training
	  • Physicians and nurses

Communication and advocacy	• increase level of general awareness of the connection between air pollution and different health impacts • provide tools and communicate results of pilots on affordability of alternatives • Develop trusted sources of information on intervention effectiveness
Finance	• Economic modelling of price structures to increase affordability of clean options in less affluent populations • Develop finance options and incentives for initial purchase of clean alternatives

The Government has started developing the capacity to monitor environmental impacts. However, expansion of technical capacity, human resources and enforcement abilities more rapidly is required to address high air pollution concentrations systematically. In order to achieve the best results, there is a need to prioritize policies identified in the action plan based on the cost effectiveness of the measure in reducing health impacts as the primary metric. Also needed is a long-term strategic urban plan of what primary energy choices in Bishkek will look like over the next 10 years, and how these will reduce air pollution to WHO air quality targets. Development of no burn zones for raw combustion form a critical element of long term urban planning to ensure ambient air pollution concentrations are reduced upstream of current high concentration areas. However, no burn zones are dependent on the affordability, availability and acceptability of clean alternatives. To ensure a smooth transition there is a critical need to model different price points in energy pricing structures. Raising heat and electricity tariffs to cost-recovery levels will incentivize solid fuel use without pricing structures to maintain social support to the most vulnerable. While subsidies are inefficient in achieving social good, as they provide blanket financial benefits that are not targeted to the populations with greatest need, market based tiered pricing structures can be designed to incentivize behavior change in target populations. Similarly misplaced policies can result in unanticipated drivers of behavior toward increased use of coal and air pollutions emissions. Thus, price points need to be carefully evaluated to provide adequate incentive to ensure affordability and acceptability of clean alternatives without wasting resources. For example, while a population price point for gas consumption can be maintained for purchasing imports, the price to the consumer can be structured in a tiered manner to incentivize low-income houses that have limited needs and resources to fill space heating requirements, while at the same time disincentivizing over consumption in the more affluent with higher pricing tiers. The average price paid to the producer however remains the same. Similarly, energy efficiency and new technology play a joint role in reducing emissions. Energy efficiency measures including window, wall and roof insulation are needed to reduce energy demand in single homes, which allows clean technologies to be more affordable, and available resources to supply more homes. Technology solutions such as air-to-air heat pumps require piloting to demonstrate affordability and acceptability that can be used to educate the wider population. Purchase price incentives and finance options are a priority for newer technologies. In central urban districts turn down ability and thermostats are required for central heating in apartments. While installed in new apartments, technologies that allow retrofitting older apartments is a priority in order to expand the number of buildings district central heating can supply.

While long term urban management strategies are required to control air pollution including the pricing and mix of fuels available, other measures are also necessary to achieve the goal of healthy environments in Bishkek including a building of capacity within municipal and state governments combined with clear mandates, improved technical capability of regulatory agencies in emissions monitoring, improved research capacity, and open sharing of information combined with improved reliability in both health and environmental data. Finally social transition to reduce air pollution emissions require a well-developed communication strategy using modern communication techniques targeted at increased awareness of population and government including recognition of the role played by burning raw coal in inefficient stoves and the urgency to address air pollution-related impacts. In addition, communication and education strategies are requires for professional groups such as teachers in training colleges and medical professions to develop consistent messaging as trusted sources of information, combined with engagement of the private sector.

Transitions in primary energy to reduce air pollution require a data driven strategic plan and political motivation to achieve. While some of these transitions in other countries have been relatively rapid, others have progressed more slowly due to political motivation and resources. In the meantime, however, it is important to recognize that there are strategies that can be implemented to reduce exposures and mitigate some of the health impacts in the current generation of children that are growing up in Bishkek. Key measures to reduce impacts include targeting pregnancy and early days of life for exposure reduction strategies such as home air purifiers during pregnancy, ensuring young children can learn and play in environments that limit lung damage and growth impairment, ensuring adequate nutrition during pregnancy, during the first 1000 days and that locally grown antioxidant fruit and produce feature in school children's nutrition. Finally, continued work to reduce prevalence of tobacco smoking in indoor environments will ensure health benefits from reducing air pollution emissions are realized in the population.

4.1. ENTRY POINTS AND OPPORTUNITIES FOR ACTION BY DEPARTMENT

Although activities below have been grouped by departments that can play a convening role, air pollution is a multi-sectoral issue that touches all parts of government and society. As a result, coordination with other government and non-government units that can provide technical support and additional resources is a component of cost-effective strategies to reduce air pollution, including identification of multilateral and bilateral partnerships.

ENTRY POINT 1: Programmatic consistency and coordination

With increasing engagement of multilateral and bilateral agencies to address the air pollution situation in Bishkek, there is a need for coordination of actions for programmatic consistency and cost-effective use of time and resources. The inter-ministerial committee to address air pollution chaired by the mayor could play such a coordinating role. Interventions should be carefully evaluated and prioritized considering economic and technical feasibility, effectiveness results from pilot studies, health benefits per unit cost to implement intervention, and the projected timeline for implementation. Evidence based policy making requires the synthesis of environmental information and health data to allow evaluation of policy options, and the training, human resources and data quality to achieve this is an important priority. There are a number of open access tools distributed by the WHO (e.g. CHEST[xlv]) that may be used to evaluate cost benefit of air pollution interventions, and the WHO Urban Health

xlv https://www.who.int/tools/clean-household-energy-solutions-toolkit

Initiative has developed approaches to assist governments in evidence based policy making through scenario evaluation[xlvi] which can be used to evaluate policies in Bishkek. In addition to prioritization of interventions and reviewing progress on initiatives, biannual meetings that engage implementing partners and funding groups allow both sharing of information, coordination of actions and reduces the number of meetings undertaken with government counterparts by individual stakeholders.

ENTRY POINT 2: Communication strategies

Communication about strategies to reduce air pollution exposures with the population plays a major role where behavior change at a household level is required. Perceptions on independence, openness, reliability and transparency are key pillars in developing trusted sources of information. Development of a communication strategy is recommended with clear objectives and messages, disseminated through a range of channels to engage different population sectors, including active engagement of social media, and websites with key information messages. Increased investment in audiovisual engagement is recommended to boost community interest and participation, including developing plans for multi-stakeholder engagement to foster public-private partnership.

ENTRY POINT 3: Coal burn free zones

Promotion of burn-free zones is a priority for urban areas to reduce household and facility level emissions along with promotion of cost-effective alternatives. Similar approaches to creating smoke-free zones played a major role in reducing London's fuliginous smog episodes, along with relocating power generation plants and heavy industry outside the urban area[45]. Increasing penetration of air-to-air heat pumps in urban areas should be accelerated along with solar water heaters. Solar water heaters have been instrumental in Australia[46], Africa, India, China and Nepal[47] among others for reducing electricity demand.

ENTRY POINT 4: Improved health surveillance

Improvements are needed in reliability of eHealth data to allow detailed evaluation of the incidence of air pollution related diseases on an ongoing basis in epidemiologic investigations as a key part of public health strategies for disease tracking and evaluating the impact of actions to mitigate air pollution exposures. The utility of health data collected by the MOHS could be significantly improved through: a) accelerating improvements on eHealth information systems. Improvements in the quality of collected health data can be accomplished with greater awareness of primary physicians of the importance of ICD 10 codes in disease tracking and a continued trajectory toward point of care data entry systems similar to those used in western industrialized countries. In the interim, streamlining data collection channels, improved knowledge of diagnoses criteria used by code entry personnel to distinguish between different codes, continuing training of code entry personnel and systematic cross-validation of code entry are important tools to improve data quality; b) Improvements in epidemiological surveillance information can be achieved by building expert teams and training of SES staff in epidemiological methods and the need to record eHealth data in formats that facilitate systematic analyses. Facilitating both time commitment and financial support of staff to enroll in online MPH programs, or in-person MPH programs, that include training in R and statistical methods in epidemiology would improve staff knowledge and capacity; c) Continuing professional development in relation to air pollution can be

xlvi https://www.who.int/initiatives/urban-health-initiative/pilot-projects/accra integrated as part of the program of the Kyrgyz Government on Public Health Protection and Health Care System Development for 2019-2030 “Healthy Person - Prosperous Country,” or State Program of Health Development 2030, which provides a mechanism to provide quality continuing professional development (CPD) materials, facilitates delivery of targeted CPD materials addressing quality gaps, and permits monitoring of effectiveness of targeted CPD efforts through development of an electronic platform for CPD learning and strengthening required structures and processes, such as capacity building for sustainable online CPD content development.

Doctors and nurses provide a primary avenue for engaging the population and providing key information about impacts of air pollution on disease outcomes and strategies to mitigate exposure. For example, programs that include the loan of air filtration devices during pregnancy can be initiated through maternal health visits, along with information transfer on the importance to the child of reducing exposures and providing adequate nutrition in minimizing disease and adverse cognitive outcomes, which both affect life trajectories and future earning potential. Training of both doctors and nurses in air pollution related disease during initial qualification and post qualification medical education programs allows medical personnel to respond directly to questions as trusted information sources on health. In addition, provision of this information in waiting rooms, and on health websites through audio visual programming allows direct contact and education of the population at time where there are few other entertainment sources.

ENTRY POINT 5: Improvement environmental measurements

Hydromet is the leading authority on ambient concentrations of air pollution in Bishkek. Current ambient air pollution data is fragmented, has a high failure rate for quality control objectives, and does not provide an adequate evidence base for policymaking. There is a need for additional monitoring stations, increased human capacity building, open data repositories and training in analysis techniques. Given large differences in $PM_{2.5}$ concentrations in different city neighborhoods and the need to provide information for air quality planning and management, intervention evaluation and AQI metrics to inform the population, there is a need to expand $PM_{2.5}$ low-cost sensor networks combined with support and logistics associated with achieving high data quality objectives and maintenance of the networks. Where possible, expansion of the multipollutant continuous ambient air monitoring (CAAM) network to provide high quality reference data through careful site selection is also recommended. Primary quality assured air quality and meteorology data that have been collected using taxpayer funds should be publicly available as these data are crucial for analyses that provide the foundation for science-based policymaking and the public has invested already in their collection.

In addition to ambient measurements modernization is needed in national ambient air quality standards to be consistent with international norms, and in emission standards for stationary and non-stationary sources. Increased technical capacity and equipment is needed for emissions measurement from industrial facilities, which includes training, annual budgets for staff, maintenance and consumables. Law 28 states “Emissions of pollutants to the atmospheric air by stationary sources shall be allowed in accordance with legislation of licensing and permits”[xlvii], and approved maximum and average daily permissible emissions limits be stored in the state body for environmental protection and at the enterprise. However, it is not clear that the technological, regulatory and enforcement structures to support these laws are present. Currently under the “Instruction on protection of atmospheric air” economic entities are responsible for instrumentally determining the types and amounts of pollutants and once every five years, conducting an inventory of emissions of pollutants into

xlvii https://www.fao.org/faolex/results/details/en/c/LEX-FAOC159545/

the atmosphere and submitting the results of the inventory to state environmental protection bodies. Experience in other countries has shown, however, that independent monitoring of emissions from economic entities typically by the Environmental Protection Agency is required on a routine basis without warning of when site visits will occur, combined with real-time emissions reporting from larger facilities. Continuous reporting of data from large scale industrial facilities with on-site air pollution monitoring for $PM_{2.5}$ will become a necessity.

Routine monitoring of mobile source emissions on an annual or semi-annual basis remains an important tool for control of air pollution in western industrialized nations. Dynamometers to routinely determine vehicle emissions allow for significantly polluting vehicles with a mechanical malfunction in the vehicle fleet to be detected. Experiences in other nations have shown that the 10% of malfunctioning vehicles in the vehicle fleet contribute 90% of the emissions, which can be controlled through vehicle emissions testing. While household winter heating currently dominates $PM_{2.5}$ air pollution concentrations in Bishkek, once increased controls on these sources are exercised, transportation and industrial emissions will play a greater role in urban air pollution concentrations, and the 2030 Agenda for Sustainable Development Goals are unlikely to be met without addressing these sectors. The Kyrgyzstan "Instruction on protection of atmospheric air" includes provisions that vehicles must be tested for emissions compliance in accordance with established standards before sale and during periodic inspections by state control bodies. Since the abolishing of a vehicle inspection system[xlviii], it is unclear if routine monitoring of emissions is yet to be implemented. Historically in the region there has been little attention in terms of policy making and compliance systems[xlix] resulting in a lag in implementation and monitoring. There is a need to establish effective routine vehicle testing and compliance regimes. Current published regulations rely on outdated Russian standards from 1975 to 1987, while Russia itself has moved to implement EURO standards. Four other countries in the Caucasus region have also implemented EURO standards: Armenia, Georgia, Kazakhstan, and Uzbekistan. The standards used are GOST 17.2.2.03-87, which defines the contents of carbon oxide (CO), hydrocarbons in burnt gases of vehicles with gasoline engines, and GOST 21393-75, which covers black smoke of burnt gases of vehicles with diesel engines. To develop strong emission control mechanisms, updating of environmental of standards to EURO equivalency combined with significant investment in human capacity, training and modern monitoring equipment will be required, which will also form the basis for robust emission inventories for modeling purposes.

ENTRY POINT 6: Awareness and education

A primary avenue to transfer public health information into communities is through school and university education programs. Education materials that include strategies to reduce air pollution can be included for use in the environmental component of the curriculum that includes protecting environment, health and welfare, and climate change. Similarly, talks in schools on tobacco smoke should incorporate other air pollution messages. Audio-visual materials on air pollution and its health impacts are a priority for use in schools, along with comic books with air pollution messages similar to the 2019 UNDP comic book on violence.

In addition to education as part of the environmental curriculum, strategies to include air pollution related topics in science fairs for ages from primary to high school engage students in the area, and are already . Similarly, developing art competitions with a theme of air pollution and its impacts on health with relevant background materials, art supplies and prizes can help to engage students and increase awareness of environmental risks in their communities. Engagement of art with environmental issues is already emerging in Bishkek

xlviii https://www.jica.go.jp/english/our_work/social_environmental/id/asia/central/kyrgyz/c8h0vm0000anzlqt.html

xlix https://rec-caucasus.org/publication/fuel-quality-and-vehicle-emission-standards-overview/

e.g. The ecological art festival "TRASH-3: art + ecology"[l], Kyrgyz artist Aida Sulova confronts waste problem in Bishkek[li]. Enhancing these messages and engaging youth in these messages all form part of strategies to engage the population on the harms that air pollution can cause.

ENTRY POINT 7: Technological evaluation

Feasibility studies and pilot studies of the effectiveness of air-to-air heat pumps, energy efficiency and other clean heating technologies are very important to evaluate user acceptability and affordability, and thus effectively reduce indoor air concentrations and emissions. Robust monitoring and evaluation, similar to the successful pilot study of air-to-air heat pumps in Ulaanbaatar[48], provides detailed information on indoor temperatures during the winter heating season, corresponding outdoor temperatures, user perceptions and cost comparison with other heating types. Pilot studies can avoid costly and expensive dissemination of interventions that fail to deliver. Evaluations have added benefits of providing communication features, data for household modelling of health impacts and provide technical recommendations of successful approaches for wider dissemination. Independent monitoring and evaluation of interventions through academia, or expert groups also provides a critical tool to increase confidence of users that investments will deliver on assurances.

ENTRY POINT 8: youth engagement

Youth represent a key component of increasing awareness of air pollution health impacts. While youth involvement in Kyrgyzstan is growing but still needs strengthening[lii]. Increasing the scope and range of youth advocacy groups could be expanded through greater awareness of air pollution mitigation technologies, expansion of networks, and seed funding for small business opportunities linked to environmental health. Expansion of the capacity of advocacy groups by connecting them with UNICEF programs upshift, start-up, podium, U-report and ponder would significantly strengthen capacity. U-report was launched in 2021 by the Ministry of Culture, Information, Sports and Youth Policy of the Kyrgyz Republic and UNICEF as the 2nd country in the Central Asia region to launch the program. U-Report is a free digital tool which empowers young people around the world to engage with and speak out on different issues. Various polls are run by U-Report soliciting opinions or experiences of youths. Information received is shared back with communities and connected to policymakers. Attracting youth interested in environmental health and air pollution could be increased through the use of air pollution as a recruitment tool for U-reporters at fairs and events, and the increasing presence of U-reporters at teacher training colleges. In addition linking to other multilateral and bilateral youth advocacy programs e.g. GIZ Prospects for Youth, USAID, Demilgeluu Jashtar will significantly accelerate the potential for youth engagement to participate fully in addressing air pollution concerns, particularly if they capitalize on influencers and target them with specific messages and calls to action. The Demilgeluu Jashtar project, although only implemented in a few Oblasts[liii] aims helps youth to be more active in their communities as well as be better prepared for the labor market through skill training on leadership, life skills, entrepreneurship, and professional development, and working with young people to help them solve issues and develop initiatives in cooperation with local governments that support their communities.

l https://bishci.com/en/2021/09/24/the-ecological-art-festival-trash-3-art-ecology-will-be-held-in-bishkek-on-september-25/

li https://www.huffingtonpost.co.uk/entry/aida-sulova_n_1647615

lii https://www.giz.de/en/worldwide/80125.html

liii https://www.usaid.gov/kyrgyz-republic/fact-sheets/enhancing-employability-and-civic-engagement-youth

Increasing advocacy networks can be accelerated through a combination of measures including supporting and promoting influencers in social media groups that assist in disseminating key environmental information more widely, linking green networks, teacher training colleges, youth advocacy and university groups with NGO advocacy groups to provide a strong network, and developing the financial resources to support workshops and actions on air pollution. Teacher training colleges can play a significant role as post-qualification teachers have a continuous presence in the community and are assigned to schools often in hard to access locations. Development of curricular activities, clubs and networks focused on environmental health issues during their stay in teacher training colleges would enrich student experiences, particularly with audiovisual materials on air pollution and health impacts that can provide an aid in instruction.

Maintaining an online resource of audiovisual material for awareness-raising combined with authoritative information on health impacts and best practices for mitigation is an important component of increasing capacity of all advocacy groups, which can also be used by teachers as aids in curricula on environmental health, and used in teacher training colleges. Nurses and midwives would also benefit from the development of air pollution information, similar to other health information.

Use of currently popular messaging apps, rather than new app development, for sharing of air pollution issues would have greater penetration, especially if combined with the development of communication strategies to avoid audience fatigue but maintain an active presence. A combination of regular U-report queries, a systematic approach to disseminating information on strategies to reduce exposures to air pollution, and innovation opportunities in environmental health is likely to have greater acceptance.

Similarly, supporting youth ambassadors from abroad to share experiences on air pollution and environmental health through peer-to-peer sharing will significantly increase impact. Convening a regional Youth Summit on environmental health topics would provide momentum to youth groups in Bishkek that could be hosted in the Youth Center established by the State Agency for Youth, Physical Culture and Sports with the support of international development partners - UNDP, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and United Nations Office on Drugs and Crime (UNODC). Similar Youth Forums and 'Social Make-a-thons' as part of Demilgeluu Jashtar, engaged more than 400 young activists and 39,450 viewers in in Bishkek (2018) and Jalal-Abad (2019) with the goal of inspiring young people to become leaders, entrepreneurs, and active members of their communities[liv].

Increasing youth participation in University research, internships, innovation hubs and programs to facilitate small business startups increases local engagement and promotes greater awareness of issues that directly affect youth health.

liv https://www.usaid.gov/kyrgyz-republic/fact-sheets/enhancing-employability-and-civic-engagement-youth

4.2. COORDINATION WITH OTHER PROGRAMMATIC ACTIVITIES

WASH

Water, sanitation and hygiene (WaSH) shares the same constellation of risk factors as air pollution, yet investigators in air pollution and WaSH, rarely interact despite having similar training and using similar methods to evaluate interventions in the same vulnerable populations [49]. Wash and Household air pollution also suffer from the same failure of policy measures to invest in clean reliable energy, water, and sanitary sewerage at the household level because of unwillingness to see these costs as social investments in the same way as schools and primary health care[50]. Actions promoted to reduce risk factors in both these areas can thus benefit from actions at scale.

Nutrition

Nutrition during pregnancy and early life plays a major role in vulnerability to diseases immediately after birth and throughout the lifespan. FAO and UNICEF are jointly supporting the Kyrg Republic to develop food based dietary guidelines with initial steps on analysis and data collection. Since many of the chronic diseases cause by air pollution are mediated through chronic inflammation, air pollution effects in the body can be partially mitigated through antioxidant uptake. Food-based dietary guidelines can incorporate antioxidant intakes. Evaluating local foods that are high in antioxidants and promoting them as beneficial to mitigate some air pollution impacts as part of existing nutrition programs can achieve both nutritional goals and reduce disease burdens. Programs to improve antioxidant nutrition, however, are not sufficient to substantially remove health impacts from air pollution, and thus should not take the place of measures to reduce air pollution emissions. Rather, these programs have wide ranging health benefits, and are an interim measure while air pollution concentrations are reduced.

Improved environmental health data and indicators (MICS)

Multiple indicator cluster surveys provide an essential tool in increasing the range and quality of survey information gathered by countries, and an essential resource for many agencies. Providing input for additional questions on DHS/MICS for implementation during the next survey round is important to understand better the air pollution in Bishkek and wider Kyrgyzstan, especially in relation to household use of secondary fuels for heating.

UNICEF headquarters maintains a series of global databases for monitoring implementation of the SDG global indicator framework related to women and children's health[lv] where UNICEF's role is in supporting member states to collect, analyze and report on child-related SDG indicators at national and global levels. While WASH and nutrition are included as SDG indicators, air pollution exposures, which have a much higher global burden of disease in children is not mentioned as a core indicator for child health, although air pollution impacts child cognition, school performance, lung growth, school absence, and is the largest environmental health burden experienced by children. Similarly, while Child-centered Risk Assessment modules include HIV, nutrition and WASH, air pollution is not included as a module although accounting for more ill-health than the others combined.

lv https://data.unicef.org/resources/briefing-notes-on-sdg-global-indicators-related-to-children/

Healthy Environments for Healthy Children

In 2021, UNICEF rolled out the Healthy Environments for Healthy Children (HEHC) Global Framework[lvi] which identifies five groups of environmental hazards that impact on children's health: toxic metals, toxic chemicals, hazardous waste, environmental risks, and climate change. Air pollution is the leading environmental risk causing significant burdens of disease and mortality among children especially in LMICs. UNICEF key messages on air pollution[lvii] and video[lviii] provide a framework for UNICEF engagement in reducing exposures to air pollution, awareness on the impact of air pollution on children's health, and actions that can be undertaken by each sector- governments, private sector, civil society, care-givers. In addition an on-line "Introductory Course on Children's Environmental Health" is being developed that could be used to train frontline health workers on prevention, detection, treatment, care and management of air pollution related diseases.

First 1000 days

The first 1000 days of life, which encompasses the time period during a woman's pregnancy and through the child's second birthday, is a critical period for a child's lung, brain and immune system development when the foundations of health and welfare across the lifespan are established. Children who are well-nourished during this period do better in school and as adults, earn twenty per cent more in the labor market, and are ten per cent more likely to own their own businesses. Malnutrition weakens this foundation leading to earlier mortality and significant morbidities such as poor health and reduced neurodevelopment. UNICEF's Early Moments Matter campaign aims to raise awareness about the importance of healthy brain development in the earliest years of life, increase investment by governments and businesses in Early Childhood Development programs, policies and services, and support parents and caregivers to give their children the best start in life. Acknowledgement of the risks posed by air pollution exposures in the first 1000 days, including significant impairment of neurodevelopment, reduced lung growth, and increased risks of pneumonia should be better acknowledged and incorporated into the messages on Early Moments Matter.

Social protection has played a key role in Kyrgyzstan's transition to a market economy, introducing targeted social assistance and labor-market programs and maintaining the social insurance system that existed prior to independence[24]. Social protection is the largest component of public spending, accounting for more than expenditure on health and education combined, although targeted social assistance programs, are small due to the large costs of the pension system[24]. The process to reform state benefits for households with children by combining universal and poverty-targeted support, particularly during pregnancy, provide a mechanism to both educate populations on air pollution impacts and also provide incentives for behavior change. Activities to reduce air pollution exposures can have significant benefits during this period.

Communication for development, Youth advocacy

1. Internet of Good Things (IoGT)

Internet of Good Things is a mobile-ready website that enables free access to content without data charges in 63 countries in 13 languages. IoGT supports increased access to information for parents/caregivers, adolescents/youth and service providers/front-line workers. Use of

lvi https://www.unicef.org/documents/healthy-environments-healthy-children-key-messages

lvii https://www.unicef.org/media/123156/file/Childhood_Air_Pollution_Key_Messages_2022.pdf

lviii https://www.youtube.com/watch?v=vhSV31IGhLc the platform to host key air pollution related messages can enhance awareness of youth/ parents and caregivers with trusted air pollution information.

2. Upshift

Upshift is a flagship UNICEF program designed to understand community challenges and design and build impactful solutions in the form of products or services.

Upshift activities on air pollution could be stimulated by the launch of a thematic workshop on air pollution. This could involve adolescents in the development of personal protection products for air pollution targeted to appeal to younger generations, such as:

- Development of air pollution mask designs fashionable for adolescents
- Development of low-cost air filtration products for rooms and spaces – see https://smartairfilters.com/cn/en/

3. Start-up

Start-up is a second gate funding program to foster entrepreneurial culture and employment for adolescents and youth through finding commercial avenues to market products developed in Upshift. Start-up could be used to support air pollution related projects and services to commercial reality in Bishkek

4. Podium

Podium is a program to teach youth to advocate for the needs and rights of their communities through the power of social change and advocacy by cultivating campaign management and advocacy tactics. Podium could be instrumental in increasing adolescent awareness of air pollution health impacts that will be experienced later on in life, and in advocating for cleaner air. Podium could also be used to increase awareness through citizen science projects using low cost air pollution sensors to measure different city environments for air pollution, investigate most polluted areas, and increase advocacy for clean solutions. Finally use of low cost air pollution sensors could be used to increase awareness of and action for public places free from tobacco smoke.

5. Ponder

Ponder is a workshop to foster media literacy and critical approaches to information to judge the value, authenticity and authority of the information adolescents encounter. Ponder could play a role in assessing claims related to air pollution, and increasing awareness of health impacts

6. U report

U-report is a program to encourage reporting by adolescents on their environment and surroundings using app and web based tools. U-report could fill in critical gaps in information from households on space heating practices, acceptability of different interventions, and other more specific data on relation to household’s practices U-report could also be a valuable tool in dispelling myths related to air pollution health impacts and air pollution technologies by:

- Developing an app/forum for air pollution advocacy
- Identifying and connect groups active/concerned against air pollution
- Dissemination of air pollution health impact data
- Action on smoke free public spaces

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

FRAMEWORK FOR IMPLEMENTATION

5. FRAMEWORK FOR IMPLEMENTATION

With finite resources to address pollution it is important to prioritize actions that are feasible in the current political and cultural context with the highest benefit-cost ratio to society. Guiding principles of actions to reduce exposures to $PM_{2.5}$ air pollution should be based on the most cost-effective actions to reduce health impacts, since the principal concerns about air pollution are the health burdens imposed on society. Prioritization should be guided by an evidence-based assessment of sources, disease burdens and health inequities to target the most vulnerable populations, particularly women and young children.

While ultimately the air pollution situation in Bishkek will not be resolved until household burning of raw coal is eliminated, there are a range of short-term, medium-term, and longer-term actions that are possible to achieve this goal. Table 13, 14 and 15 show a range of suggested actions that could form the basis for such a road map to reducing air pollution burdens in Bishkek over the short, medium and long term, respectively.

While the identification of the suggested organizing units reflects the Kyrgyzstan organization that could play a principal convening role, air pollution is a multi-sectoral issue that touches all parts of government and society. As a result coordination with other government and non-government units would be important to accomplish each of the action items identified below. In addition, since action items will require technical support and additional resources, identification of multilateral and bilateral partnerships to support action items would play a critical role in implementation.

SHORT-TERM ACTIONS (6 MONTHS TO 1 YEAR)

Table 13: Strategic action plan: Short-term actions

Action	Suggested organizing unit	Key outputs
Overall coordination across sectors Expand air pollution control districts beyond municipal boundaries Formalize the strategic road map over 10 years Modernize standards for ambient air pollution, mobile, and stationary sources	Inter-ministerial steering committee Chaired by the Mayor to address air pollution	Strategic road map Modernized standards Consultation process

Economic modelling of the impacts of energy pricing on exposures and health impacts of air pollution	Ministry of energy	A report detailing findings shared publicly
Alerts for air pollution	City government	Develop framework for alerts Develop communication strategies with cell phone providers
Promotion of energy efficiency measures	National and City governments	Reduced household energy consumption making clean alternatives more cost competitive Controlled indoor temperatures releasing capacity for expansion of central heating
Increase citizens' awareness of the sources and health impacts of air pollution	Public health agency National and City governments	Launch communication campaign
Increased education on sources and health impacts of air pollution	Ministry of Education	Audiovisual air pollution materials developed for use in schools Audiovisual air pollution materials developed for use in teacher training colleges Increase research funding for universities on air pollution School art and science competitions focused on air pollution
Facilitate open sharing of air pollution data and information that impacts air pollution policies	National and City governments	Development of information hubs Require open data policies from government Require open data policies from facilities/industries when requesting emissions approval

MEDIUM-TERM ACTIONS (1-2 YEARS)

Table 14: Strategic action plan: Medium-term actions

Action	Suggested organizing unit	Key outputs
Improve environmental monitoring	Ministry of Natural Resources, Ecology and Technical Oversight of the Kyrgyz Republic	Increased number of air quality monitoring sites Improved continuity of data Training in data quality assurance
Improve registration in informal areas to deliver healthcare- hard to know health impacts	City and State Government Ministry of Health	Registration of individuals Improved data collection for eHealth
Monitoring of emissions from facility level heat boilers and industries	Ministry of Health of Kyrgyzstan and Ministry of Natural Resources, Ecology and Technical Oversight of the Kyrgyz Republic	Data to estimate urban contributions
Include air pollution in the outcome measures for National strategic plan for prevention and control of NCDs	Ministry of Health	Metrics to reduce NCD burden from air pollution exposures
Improve awareness in maternity wards of impacts of air pollution during pregnancy	Ministry of Health	Training primary physicians of the importance of ICD 10 codes Develop continuing education programs for nurses Incorporate loan of air filters for use in second and third trimester
Improve epidemiological surveillance information on air pollution-related diseases	Ministry of Health	Improved eHealth data quality Financed attendance of MPH programs with staff training certificates
Expand the capacity of youth advocacy groups	UNICEF; NGO; Business groups	Online resource of audiovisual material Online resource of authoritative information on health impacts and best practices for mitigation Supporting influencers in social media groups Youth summit on air pollution with youth ambassadors

LONG-TERM ACTIONS (2-5 YEARS)

Table 15: Strategic action plan: Long-term actions

Action	Suggested organizing unit	Key outputs
Create of Coal burn-free zones in urban areas	National and City governments	Incentive plans for replacement with clean alternative Availability of affordable alternatives
Expansion of district central heating	City governments	Promotion of energy efficiency measures indoor temperature regulation retrofit turndown ability
Pilot clean energy alternatives	Ministry of Energy, Ministry of Health of Kyrgyzstan and Ministry of Natural Resources, Ecology and Technical Oversight of the Kyrgyz Republic	Report on impacts and relative costs of air-to-air heat pumps and other intervention approaches
Development of finance mechanisms to overcome cost barriers for clean technology	Ministry of finance and private institutions	Micro-finance mechanisms to overcome cost barriers
Improve ICD10 coding quality Accelerate transition to point of care data entry	Ministry of Health	Develop long term plans to improve data quality
Address waste dump emission	Ministry of Natural Resources, Ecology and Technical Oversight of the Kyrgyz Republicand City governments	Chemical characterization of dump emission Waste segregation
Vehicle emission testing	Ministry of Health of Kyrgyzstan and Ministry of Natural Resources, Ecology and Technical Oversight of the Kyrgyz Republic	Annual reports of vehicle emissions fleets
Develop incentive programs to replace inefficient vehicles	City and national government	Approved replacement incentive programs
Monitoring of emissions from household sources	Ministry of Health of Kyrgyzstan and Ministry of Natural Resources, Ecology and Technical Oversight of the Kyrgyz Republic	Data to estimate health impacts

Featured Photo from the exhibition by artist Shailo Dzhekshenbaev depicting the air pollution from landfills in Kyrgyzstan © IOM/Kyrgyzstan/2022/ Shailo Dzhekshenbaev

APPENDIXES

APPENDIX 1: METHODOLOGY FOR HOUSEHOLD LOW COST SENSOR MEASUREMENTS

Table 16. Schedule of indoor and outdoor monitoring

Week of Installation Date	Heating type					Other
	Coal without Pipes	Coal with pipes	Central Heating	Pipeline Gas	Totals	
20-12-2021	2	1	2		5	
27-12-2021		2	2	1	5	
10-01-2022	3	1		1	5	
47-01-2022	4	1			5	
24-01-2022	2	1		2	5	
31-01-2022	4		1		5	
07-02-2022	4		1		5	
14-02-2022	4				4	Kyrgyzhydromet
21-02-2022	4				4	US Embassy
28-02-2022	3	2			5	
TOTAL	**30**	**8**	**6**		**48**	

$PM_{2.5}$ residential indoor exposures were estimated using spatially interpolated $PM_{2.5}$ outdoor concentrations (Appendix 2) and residential indoor vs. outdoor concentration ratios (I/O). A residential air monitoring campaign was conducted to generate data for the I/O ratios. Over the period 22 December 2022 – 09 March 2023, indoor and outdoor air quality was monitored for nominally one week at a total of 48 residences (up to five residences simultaneously). An IQAir AirVisual Pro (AVP) monitors was placed in the main living area and an IQAir AirVisual Outdoor (AVO) monitor was placed outdoors at each residence in the study. All monitors reported $PM_{2.5}$, PM10, temperature, and relative humidity. However, PM10 measurements from nephelometer-based low-cost sensors are unreliable and should not be used. AVP also measured CO2 indoors, while AVO also measured atmospheric pressure outdoors.

Figure 29 shows an example of hourly $PM_{2.5}$ data from a residence heated using a stove without pipes. Indoor concentrations closely track outdoor concentrations, in some cases with a time lag, consistent with the dominant source of indoor $PM_{2.5}$ being infiltration of outdoor air into the dwelling. This pattern was observed for most households. For this example, the $PM_{2.5}$ indoor-to-outdoor ratio of means was 0.50.

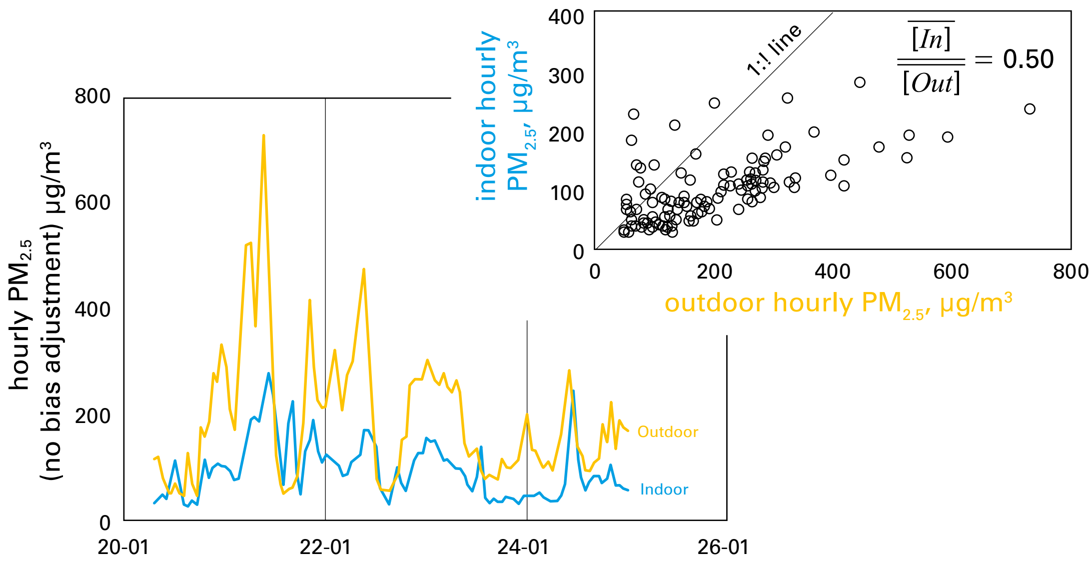


Figure 29 Time series and scattergram (inset) of indoor and outdoor PM2.5 concentrations for one residence (heating type stove without pipes)

Households were classified into four groups according to their primary heating source: stoves with heating pipework throughout the dwelling ("stoves with pipes"); stoves in the living area(s) with radiant heating only from the stove ("stoves without pipes"); connection to the central district heating network supplied by the city's central heating and power plant ("central heating"); and connection to the natural gas distribution network ("pipeline gas").

APPENDIX 2: METHODOLOGY TO ESTIMATE PM2.5 SURFACE GRADIENTS ACROSS BISHKEK

Spatially- and temporally-resolved $PM_{2.5}$ concentrations across Bishkek were needed to drive the exposure estimates. This study used the low-cost air quality sensor network funded by the Asian Development Bank (ADB) and installed and operated by Kyrgyzhydromet. This 49-site network features $PM_{2.5}$ and NO2 monitoring using Clarity S-Nodes (Berkeley, CA/USA). Network data for the period July 2021-June 2022 were aggregated to hourly averages. The hourly data were validated and censored to remove sites with less than 50% daily data completeness for one or more of the three seasons (Winter = November-January; Summer = April-September; andTransition = February, March, and October), which resulted in a reduction in number of sites from 49 to 37. One additional site (AX6R0874) was removed because of presumed microscale emissions influences leading to very high concentrations and a diel pattern inconsistent with all other sites in the network. Clarity $PM_{2.5}$ low-cost sensor raw data were bias adjusted using US Embassy Bishkek reference monitoring data; Clarity $PM_{2.5}$ raw data were divided by 1.6 for the summer season and 2.5 for the transition and winter seasons.

Network-wide data analyses were conducted using a geographic information system (ArcGis Pro, Esri, Middleton, MA/USA). Season-specific daytime (8:00 to 17:00) and nighttime (17:01 to 07:59) monitored $PM_{2.5}$ concentrations across the network were interpolated by kriging. Kriging estimates values at a given point by computing a spatially weighted average of the known values of the function in the neighborhood of the point to produce a best linear unbiased estimator in a manner similar to regression analysis. For example, Figure 27 shows the winter season all-hours (daytime and nighttime) kriged surface. Subsequently, outdoor $PM_{2.5}$ concentrations were extracted from these surfaces using GPS coordinates for the surveyed households.

The one-year average $PM_{2.5}$ kriged surface was combined with 1 km resolution year 2019 population estimates (LandScan, Oak Ridge National Laboratory, USA). Figure 30 shows outdoor $PM_{2.5}$ distribution for the 2019 population distribution (red) along with distributions for the households (green) and residents (blue) in the household survey. Mean $PM_{2.5}$ concentrations (circles) were 35, 36 and 40 $\mu g/m^3$ for the survey households, survey residents, and 2019 population, respectively. Approximately 10% of the city's population resided in areas with $PM_{2.5}$ outdoor concentrations exceeding 60 $\mu g/m^3$ – twelve times the WHO Air Quality Guideline.

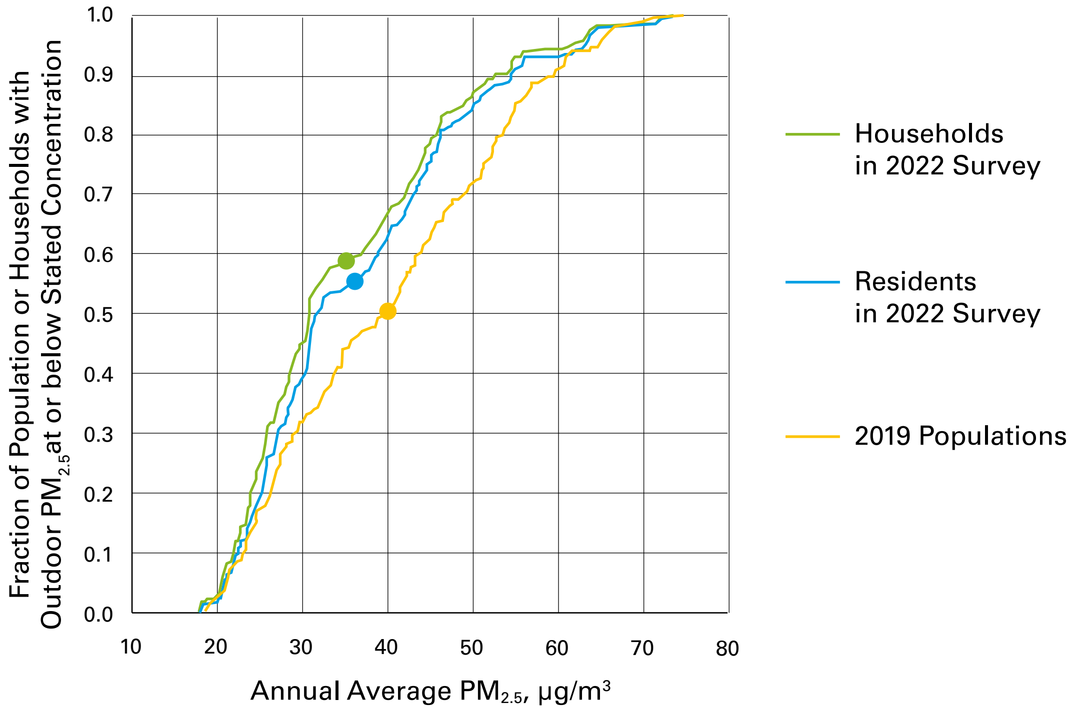


Figure 30. Outdoor $PM_{2.5}$ distribution for the 2019 population distribution (red) along with distributions for the households (green) and residents (blue) in the household survey.

APPENDIX 3: METHODOLOGY FOR HOUSEHOLD SURVEY SAMPLE SELECTION

The number of respondents in each strata (oblast) was calculated to provide 95 percent confidence with under 5 percent margin of sample error. This will provide estimates, where we can be 95 percent confident that the real and estimate values will have a variance around at +/-4.9 percent. The formula for the calculation of the sample size for each stratum (oblast) is following:

$$n = \frac{NZ^2 P(1-P)}{(N-1)\varepsilon^2 + Z^2 P(1-P)}$$

Sample design

The household survey used representative multistage stratified sampling similar to that used in MICS and national surveys in Bishkek:

- The stratum (STRATA), which included top-level administrative units - in this case administrative areas of the Bishkek city
- Primary Sampling Unit (PSU) containing the list of polling station of the Bishkek city. One polling station will be divided to 4 sub-districts
- Secondary Sampling Unit (SSU) containing the list sub-districts within each polling station
- Tertiary Sampling Unit (TSU) Systematic selection of the households, based N+3 random walk procedure
- Quaternary Sampling Unit (QSU) Random selection of the respondent in the household Using a Kish Grid.

Oblast strata:

Primary Sample Units (PSU) were the polling stations within each administrative district of the Bishkek city, Secondary Sample Units (SSU) is the sub-division, each polling station was be divided into 4 (number of sub-divisions should be the same in each polling station), Tertiary Sample Unit (TSU) is the selection of the households to be surveyed. lastly it is a random walk for a household selection and random respondent selection in a household to be implemented.

Administrative Districts

There are 4 administrative districts of Bishkek city: Leninskyi, Pervomayskyi, Panfilovskyi, Octyabr'skyi.

PSU - Districts: Bishkek city

In Bishkek city polling stations will be used as the primary sampling unit (PSU). PSUs are sampled via probability-proportional-to-size random sampling (PPS).

SSU – Districts of Bishkek city

Each polling station will be divided into equal number of sub-divisions- SSU (4 sub-division in each).

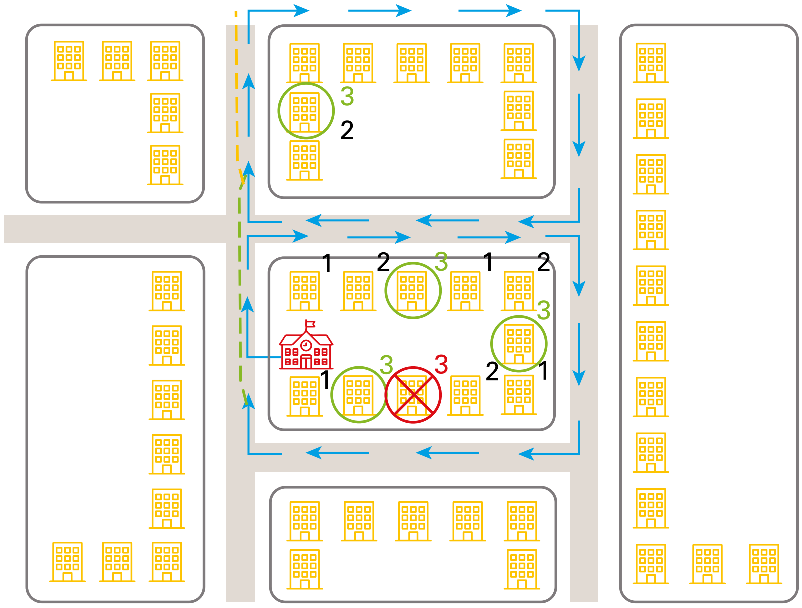
TSU – Polling stations

Within one polling station 2 sub-divisions out of 4 will be randomly chosen. In each TSU the target number of households was 20. Within areas a specific way selection procedure was adopted to ensure full coverage (distribution of respondents) of the territory and different layers of population.

QSU – Households

Households were selected randomly in a specific settlement using Random Walk procedure with Defined Interval. In each settlement, using a random approach, supervisor will define starting point (Address, street, building number), from which interviewer will have to start the movement. Starting point in two randomly selected sub-divisions within each polling station will be based near the center. One (or more depending on the size of the village) start point will be defined in different parts of village to survey various layers of population. In most cases starting point is any administrative building, road intersections, notable buildings, mosques/church.

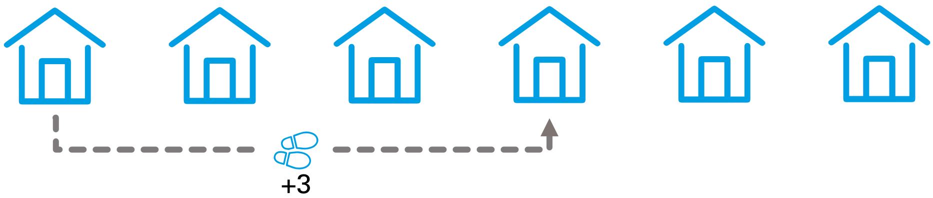
Direction of walk and selection is defined in the following way: Interviewer stands back to the main entrance of the building (starting point). Next, interviewer turn right to select the first household



Selecting the first households: Interviewer will select the first house located close to the starting point and then try to contact its residents.

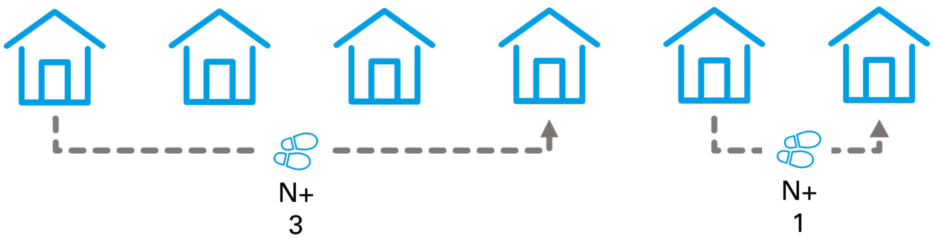
Selection of subsequent households (Successful Attempt):

Movement and step in case of private houses: Further, interviewer moves on the right side of the street with systematic interval N+3 (interviewer visits every third household as in the picture below).



Selection of subsequent households (Unsuccessful Interview Attempt)

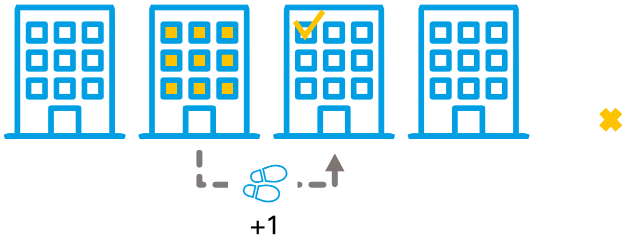
If the previous interview was not successful (interview was not conducted and no revisits are expected), interviewer replaces an unsuccessful attempt using a systematic interval N+1 (interviewer visits next household and tries to conduct interview there).



Random Walk in case of multi-story buildings:

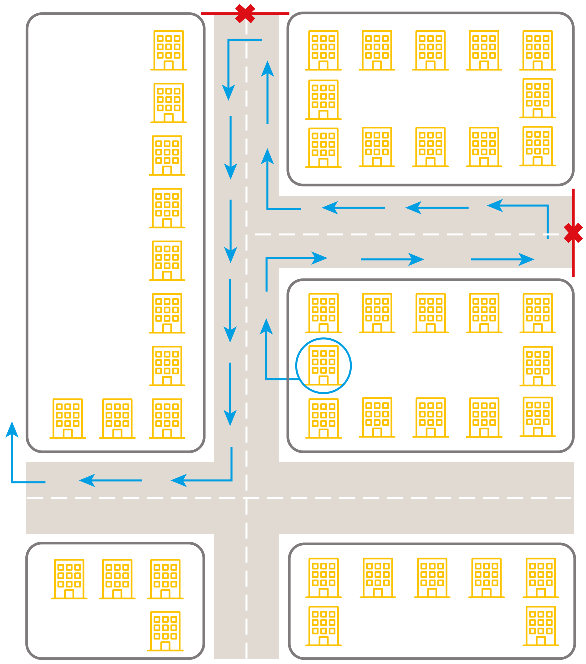
In case if a multi-story building appears in the random walk, interviewer enters the closest block of the building.

Inside the multi-story building, the N+5 systematic step is applied (interviewer reaches every 5th apartment and tries to conduct interview) after successful interview. If the previous interview was not successful (interview was not conducted), interviewer uses step N+1 (interviewer reaches next apartment and tries to conduct interview). No more than 3 households can be survey in each multistory building block. Once completed 3 interviews, an interviewer will proceed to the next multistory building block in the random walk or household if it is the private sector.



Direction in case of crossroads and dead ends

Interviewer always keeps the right-hand side of the street and approached houses/buildings located only on the right side of this street. When approaching crossroads, interviewer turns to the right. In case of dead end, interviewer goes to the opposite side of the street.



Selection of respondents inside the household:

In order to insure representative random selection, "Kish grid" technique will be used inside the household to randomly choose a respondent. According to this technique, interviewer will write down names and age of all people living in the household older than 18 years, who meet the requirements. Then, based on the interview number the respondent is selected. M-Vector uses an automated Kish Grid that is integrated into a Simpleforms software to choose the right respondent).

Survey sampling results

1. OBJECTIVES

Conduct a representative household level survey to assess:

- Income
- Household dynamics
- Housing type
- Heating stoves
- Heating fuel types and costs
- Insulation materials
- Household smoking
- Respiratory disease indicators
- Conduct a contingent valuation survey of residents of Bishkek to assess the value of a life year (VOLY) and the value of a statistical life (VSL)
- Assess the impact of respiratory disease indicators on willingness to pay

2. Respondent Selection

Survey methods: Tablet Assisted Personal Interview

Respondent selection:

Stage 1- The head of the household, the most knowledgeable on the subject of the study

Stage 2 - A randomly selected respondent using a Kish card in the same household immediately after the survey of the head of household for the hypothetical contingent valuation questions.

4. SAMPLING:

1 stage- 1007 interviews

2 stage- 601 interviews

		Number of questionnaires	
Country	**Region**	**Long questionnaires**	**Hypothetical questionnaires**
KR	Bishkek city	1007	601

50 polling stations were selected for the survey as described above.

In the southern and southwestern part of the city (Kok Zhar railway station, Archa-Beshik railway station, Gazprom Sports and Recreation complex), 60% of private households (mansions) with personal security, which made it difficult for interviewers to do a survey. As a solution to this problem, interviewers with at least 5 years of work experience who were able to do effective interviews were sent to the above-mentioned districts.

In multi-store residential buildings, an intercom is installed in 70% of the entrances, i.e. you can get into the apartments only through a code or a chip. Signs about the range of apartment numbers in the entrances served as access to households. Interviewers called and arranged an interview, went into the entrances and after the survey, the next household was selected randomly (step by step).

5. INTERVIEWERS:

Table 17. Staff of specialists involved in the project:

Position	Number
Project manager	1
Specialist of the field department	1
Interviewers/operators	26

6. INSTRUCTING INTERVIEWERS:

Date: 26 May 2022

venue: M-Vector offices Bishkek

During the briefing, the basic principles of the research methodology, the criteria for selecting respondents were described in detail and all the questions asked by the interviewers were considered in detail. Upon completion of the briefing, all field staff were provided with the necessary documentation and resources.

During the briefing, the following issues were discussed:

- Explanation of the research objectives;
- Questions about the organization and conduct of interviews;
- Discussion of each question of the questionnaire;
- Explanation of the 2 stages of the interview;
- Discussion of a hypothetical questionnaire (how to explain the essence of the questionnaire to the respondent, etc.);
- Distribution of polling stations between interviewers.

7. Quality Assurance

Control of the field work-20 %.

Listening to audio recordings: long questionnaire-198

hypothetical questionnaire- 121

Telephone control: long questionnaire-266

hypothetical questionnaire-142

Number of defective questionnaires:

1. HH questionnaire-12
2. hypothetical questionnaire-8

Reasons of questionnaire defects both for household and hypothetical questionnaires :

- survey of the least informed respondent-3 questionnaires ;
- not reading out questions- 7 questionnaires;
- incorrect wording of questions- 10 questionnaires;
- incorrect filling out of the questionnaire (the respondent says one thing, another option is marked in the questionnaire)- 20 questionnaires.

8. Questionnaire duration

Average duration:

The duration of the survey on a HH questionnaire depended on the type of household and type of heating. In multi-story buildings that used central heating questions on fuel type and cost we not asked, in private houses that used gas central heating questions on fuel type and cost we not asked.

The duration of the short questionnaire depended on the respondents' understanding of hypothetical scenarios and was conducted in a subsample of the household survey.

1. Maximum:

- long questionnaire-30 min
- short questionnaire-25 min

2. Minimum:

- long questionnaire-10 min
- short questionnaire-5 min

3. Average:

- long questionnaire-15-17 min
- short questionnaire-10-15 min

Respondent outcomes:

Table 18 Survey incompletion outcomes

	Cause	Household numbers
Failures	direct failure at the threshold	406
	No time	3
	Failure after reading questions about income	307
	Failure during process	113

Unavailable	Unavailable	51
	No one answers	356
	Uninhabited/abandoned house/no one lives there	128
	Long-term absence during survey	33
	No Adults	1
Not completed	Physically and mentally unable	2
	Did not pass screening	17
	Respondent got angry	1
Repeats	Repeat visits to conduct hypothetical questionnaire	27
	Made appointment	12

1) Repeat visits

During the May holidays many individuals were outside Bishkek and therefore it was difficult to interview the respondent chosen for the contingent valuation. The interviewers asked the head of the household the date of the respondent's return and arranged a telephone interview.

12. WORK SCHEDULE:

Table 18. Survey completion

Work stages:	Date
Compilation of questionnaires, coordination with the Customer, programming, testing	21-26 April
Instructing interviewers	26 April
Field work	26 April-26 May
Preparation of a technical report on field work	27-30 May

APPENDIX 4: METHODOLOGY FOR ECONOMIC VALUATION

The Value of Statistical Life (VSL) approach based on mortality or Value of Prevented Fatality (VPF) is widely used in cost-benefit analysis. Typically, risk reduction is estimated per population and then this estimated number is multiplied by each WTP in population. For example, if risk of death is 0.001 and in the population of 1000, everybody is ready to pay $10 then the VLS equals $10 multiplied by 1,000 hence the value of one statistical life is $10,000. Fatality-based VLS or VPF has been criticized in air pollution studies, however, as it is difficult to attribute air pollution as the sole cause of death (Bosworth et al., 2017). A more appropriate measure in these studies is the Value of a Life Year (VOLY), as it avoids this problem by assessing the value of life extension (Desaigues et al., 2011). VOLY elicits the loss of life expectancy in normal health. Hein et al. (2016) provide good overview of the history of valuation of life in relation to air pollution in the literature.

This analysis estimates country-specific value of a life year (VOLY) and the value of the healthier and longer life (VHLL) for Kyrgyzstan. VHLL is composed of two parts, willingness to pay (WTP) for an extension of one's life years (VOLY) and for an increase in the number of healthy days throughout one's lifetime (VHLL-VOLY). WTP is a well-established approach in valuing non-market goods and services (Asenso-Okyere et al., 1997; Bateman et al., 2006). It is defined as the maximum amount of money that an individual or group is willing to pay for a particular good or service. WTP can be estimated through various methods such as stated preference methods, such as contingent valuation and choice experiments, or revealed preference methods, such as the hedonic pricing method and travel cost method.

The probability of agreeing to pay is when y_i is equals to the reciprocal of a vector of explanatory variables z_i (Equation 1.). WTP can be modelled as the function □ of the vector of explanatory variables z_i with u_i as a vector of unobserved factors (Equation 2):

$$Prob(y_i = 1|z_i) \qquad 1.$$

$$WTP_i(z_i, u_i) = z_i\beta + u_i \qquad 2.$$

Probit generalized linear model for binary dependent variables was performed using the probit model in Stata 16. It is a form of the cumulative distribution function of a standard normal random variable and is used to model the probability of a certain event. Specifically, the probit model estimates the probability that a given observation belongs to a particular category or class, based on a set of independent variables. The model uses maximum likelihood estimation (Jones, 2000).

Explanatory variables

A high degree of correlation between explanatory variables in Probit generalized linear models leads to unreliable and unstable estimates of regression coefficients, and thus unstable estimates of WTP in these analyses. Since the self-reported health outcomes in the survey show a high degree of correlation with other health variables and variables such as age and income, principal component analyses was used to extract a new set of uncorrelated variables from the self reported health data (Table 19). Principal component analysis (PCA) is a statistical technique that is used to analyze data sets with multiple correlated quantitative dependent variables. The purpose of PCA is to extract the most relevant information from the data set, to express it as a set of new, uncorrelated variables called principal components, and to show the pattern of similarity between the observations.

The components were selected based on eigenvalues, and additional scree plots and loadings were evaluated to confirm "break" points and clusters. After the PCA, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was applied to check the suitability of the data for PCA. The KMO measure evaluates the appropriateness of the data for PCA by contrasting the relationship between the variables in terms of their correlations and partial correlations. A low KMO value suggests that the partial correlations are high when compared to the overall correlations, and therefore, a low-dimensional representation of the data is not advised. In these analyses the KMO measure was 0.75 indicating the data could be satisfactorily reduced using PCA. PCA was applied to the questions related to the health issues of respondents. These questions included question about breathing difficulties, asthma, dyspnea, high blood pressure and lung problems. The predicted components were then included as explanatory variables in the WTP estimation.

Table 19 PCA results

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	1.61239	0.517717	0.3225	0.3225
Comp2	1.09467	0.184647	0.2189	0.5414
Comp3	0.910026	0.130498	0.182	0.7234
Comp4	0.779528	0.176146	0.1559	0.8793
Comp5	0.603382	.	0.1207	1

Table 20 Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Unexplained
breathing issues	0.531	-0.4755	-0.0202	0.0695	0.6976	0
asthma	0.3387	0.2589	0.8952	0.1114	-0.0666	0
dyspnea	0.4089	0.496	-0.1999	-0.7334	0.0941	0
High blood pressure	0.3705	0.5276	-0.3756	0.6658	0.0004	0
Lung problems	0.5466	-0.4272	-0.131	-0.0391	-0.7072	0

Table 19 and Table 20 show that PCA analysis resulted in two main components: lung problems (Comp1) and high blood pressure (Comp2). The results were also visually inspected and confirmed using scree plot (see Figure 31 and Figure 32).

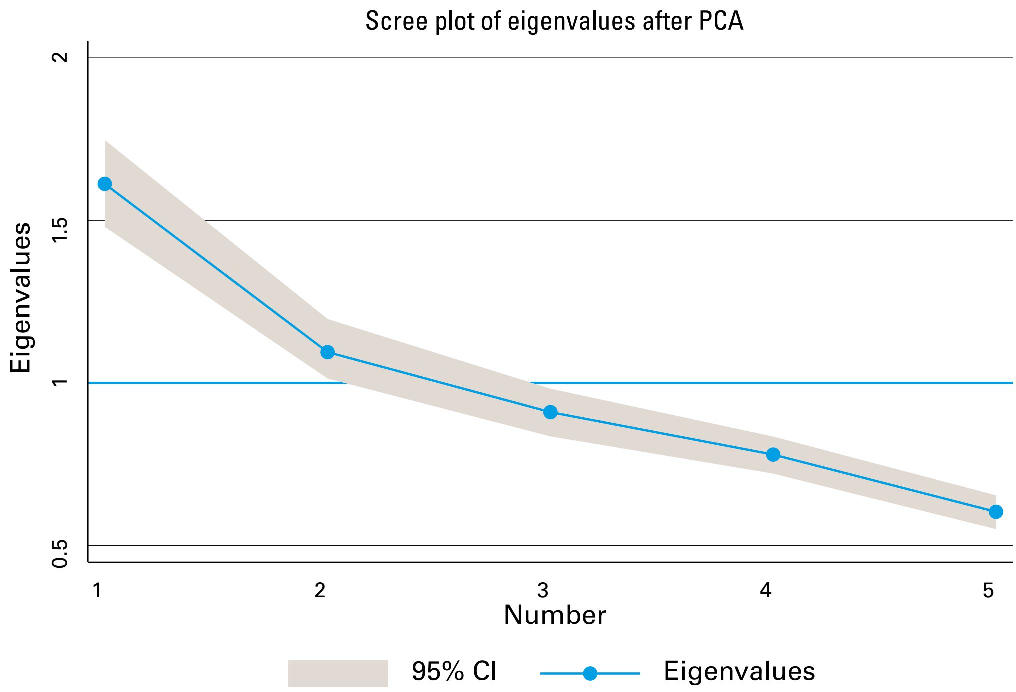


Figure 31 Scree plot of eigenvalues

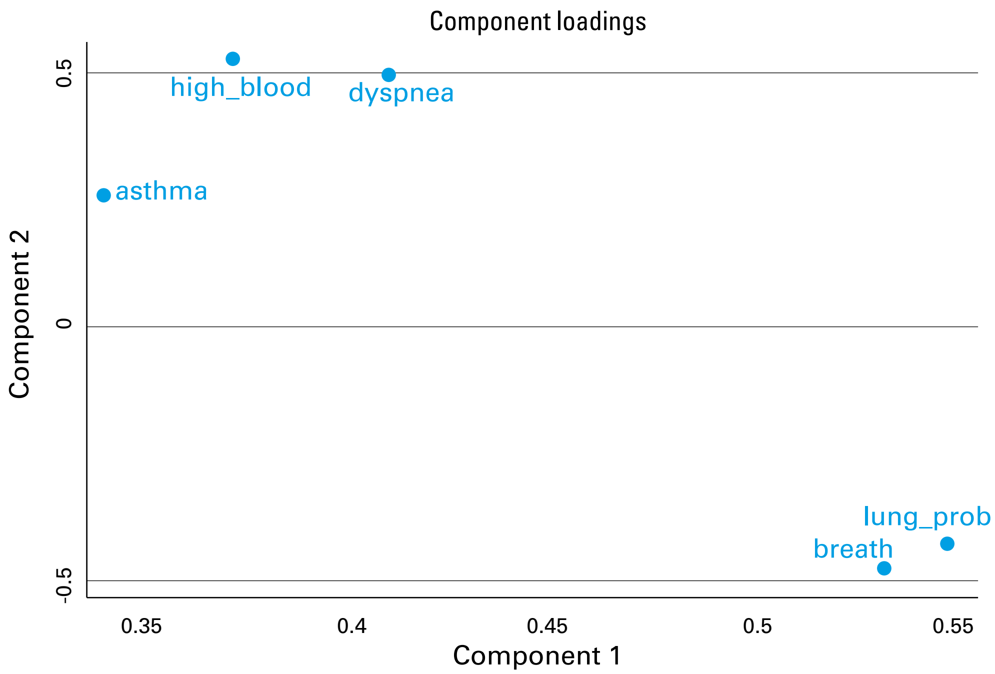


Figure 32 Component loadings

Contingent valuation

Contingent valuation method (CVM) is seen as the most appropriate way to estimate the VOLY. CVM is class of stated preference methods that directly asks respondents about what value they attach to the object of the study. It involves asking individuals directly how much they would be willing to pay for a particular good or service, or how much they would be willing to accept as compensation for its loss. The results of these surveys can then be used to estimate the total value of the good or service to the population as a whole.

CV method maybe sensitive if used inappropriately, and potential pitfalls include hypothetical bias, failure to pass the scope test, sequencing and information effects, and elicitation and starting point biases (Adamowicz et al., 1998; Arrow et al., 1993; Whitehead et al., 1992). Careful design and implementation can overcome these. The questionnaire was pretested in a pilot survey using a small number of respondents (15), and interviewers were group trained with discussions and clarification of the surveys to achieve common meaning by M-Vector, an experienced market survey research company. Further, since estimates of WTP are sensitive to the marginal gain in years of life and the degree to which the hypothetical scenarios are viewed as realistic, the surveys used 2 years as a realistic estimate for the impacts of air pollution related disease on lifespan, combined with real scenarios based on ongoing public discourse on the air pollution problem in Bishkek.

Scenarios

The survey tools used are shown in Appendix 5. Briefly, the first scenario described a situation where respondent spends a certain amount of money, for example, on maintaining a healthy lifestyle, proper nutrition, scheduled visits to doctors, the use of preventive medicine, changing place of residence to a more environmentally friendly area, respondent can avoid the occurrence of respiratory and lung related illnesses such as pneumonia, chronic bronchitis, and asthma. The avoidance of these illnesses will gain a respondent 10 more healthy days each year after age 60 and will have 2 more years added to average life expectancy of the respondent.

In the second scenario, a respondent are asked to imagine that he she spends a certain amount of money per year for household improvements (switching from coal-based heating stove to gas or central heating system, using electricity for heating, or using an air-purifier at home), so he can avoid the occurrence of respiratory and lung related illnesses in his life such as pneumonia, chronic bronchitis, and asthma. The avoidance of these illnesses will gain him 10 more healthy days each year after age 60 and he will have 2 more years added to his average life expectancy of the respondent.

Results

Table 21 shows the Probit generalized linear model for 2 year gain due to healthy lifestyle. Bid size and age had negative coefficients suggesting that higher bids and older age decrease willingness to pay. The scaled age was negatively associated with the probability to agree to pay. As expected income was significant and statistically significant, but was small because the bids were adjusted to income. Feeling pollution harm had statistically significant positive association.

Table 21 Probit generalized linear model for 2 year gain due to healthy lifestyle

Probit regression		Numberof obs		291		
		LRehi2(10)		26.34		
		Prob >chi2		0.0033		
Log likelihood = -106.93		Pseudo R2		0.1097		
2-Year gain due to healthy lifestyle	**Coef.**	**Std.Err.**	**z**	**P>z**	**(95%Conf.**	**Interval)**
Bid***	-4.2E-05	1.66E-05	-2.54	0.01	-7.45E-05	-9.58E-06
Income**	2.34E-05	1.04E-05	2.26	0.02	3.08E-06	4.38E-05
Exercise	0.45079	0.302093	1.49	0.14	-0.14131	L04288
Lung Problems (PCA)	-0.04954	0.073142	-0.68	0.50	-0.19290	0.09381
High Blood Pressure (PCA)	-0.02038	0.094948	-0.21	0.83	-0.20647	0.16572
Feels pollution harm*	0.45532	0.258973	1.76	0.08	-0.05226	0.96289
Stays inside when pollution is high	0.15609	0.213747	0.73	0.47	-0.26284	0.57503
Age (scaled)**	-0.31015	0.134646	-2.3	0.02	-0.57405	-0.04625
Squared age (scaled)	0.10315	0.095692	1.08	0.28	-0.08440	0.29070
Female**	0.42576	0.215131	1.98	0.05	0.00411	0.84741
cons	0.17899	0.368066	0.49	0.63	-0.54240	0.90039

Table 22 shows the willingness to pay for 2 years gain in life expectancy due to healthy lifestyle in where the mean WTP was 33,047 Kyrgyzstan SOM.

Table 22. willingness to pay for 2 years gain in life expectancy due to healthy lifestyle

2-Year gain due to healthy lifestyle	**Coef.**	**Std.Err.**	**z**	**P>z**	**(95%Conf.**	**Interval)**
WTP	33,047	14479	2.28	0.022	4669	61426

Table 23 shows the Probit generalized linear model for 2 year gain in life expectancy due to household improvements to reduce air pollution. Similar to the model for lifestyle changes, bid size and age had negative coefficients, and feeling pollution harm was positively correlated to WTP. Income was not statistically significant as bid amounts were adjusted to income.

Table 23 willingness to pay for 2 years gain in life expectancy due to household improvements to reduce air pollution

Probit regression	Numberof obs	291				
	LRehi2(10)	34.96				
	Prob >chi2	0.0001				
Log likelihood = -112.82312	Pseudo R2	0.1342				
2-Year gain due to healthy lifestyle	**Coef.**	**Std.Err.**	**z**	**P>z**	**(95%Conf.**	**Interval)**
Bid***	-3E-05	1.55E-05	-1.92	0.06	-0.0000602	6. 3OE-07
Income**	9.56E-07	7.77E-07	1.23	0.22	-5.66E-07	2.48E-06
Exercise	-0.1129	0.2585	-0.44	0.66	-0.6195	0.3938
Lung Problems (PCA)	0.0479	0.0731	0.66	0.51	-0.0953	0.1912
High Blood Pressure (PCA)	0.1115	0.0944	1.18	0.24	-0.0735	0.2965
Feels pollution harm*	0.4752	0.2504	1.90	0.06	-0.0155	0.9659
Stays inside when pollution is high	0.2109	0.2097	1.01	0.31	-0.2001	0.6219
Age (scaled)**	-0.4679	0.1317	-3.55	0.00	-0.7260	-0.2098
Squared age (scaled)	-0.0431	0.0908	-0.47	0.64	-0.2210	0.1348
Female**	0.1129	0.2105	0.54	0.59	-0.2997	0.5254
cons	0.6085	0.3605	1.69	0.09	-0.0980	1.3150

Table 24 shows the willingness to pay for 2 years gain in life expectancy due to to household improvements to reduce air pollution where the mean WTP was 31,660 Kyrgyzstan SOM.

Table 24. willingness to pay for 2 years gain in life expectancy due to healthy lifestyle

2-Year gain due to healthy lifestyle	Coef.	Std.Err.	z	P>z	(95%Conf.	Interval)
WTP	31,660	18098	1.75	0.08	-3812	67132

APPENDIX 5: HOUSEHOLD SURVEY

Questionnaire NUMBER ________

HOUSEHOLD ID NUMBER: ______ ______ ________ ________

ENUMERATOR TEAM INFORMATION

Interviewer		
1.1.	Name	

HOUSEHOLD LOCATION:

DISTRICT:	
STREET:	
CROSS STREET:	

DATE AND STARTING TIME:

Day	Month
Hour	Minute

NOTES:

1.HOUSEHOLD

1.1	Gender ONLY FOR OBSERVATION	1 2 -98	1. Male 2. Female -98 N/A
1.2	What is your age?	____ -98	Age in years -98 N/A
1.3	How many people including yourself live in your household?	_________Adults ≥65 _________Adults ≥18 and <65 _________Adolescents ≥10 and <18 _________Children<10	Number of people -98 -99 -98 N/A/ Refuse -99 Don't know
1.4	Do you exercise / do sports regularly?	1 2 3 -98	1. Regularly 2. A little 3. Not at all -98 N/A/ Refuse

2. DWELLING FEATURES

2.1	Indicate type of house where respondent lives.	1 2 3 4 5 6 -98	1. One-story detached house 2. Two-story detached house 3. One-story attached house 4. Two-story attached house 5. Apartment: (indicate respondent's floor ____________)- INTERVIEWER: GO TO 6.1 6. Other (Specify) ______________ ____________________ -98 N/A /Refuse
2.2	How many rooms does the house have including kitchens and living rooms?	_______ -98	Number of rooms -98 N/A/ Refuse
2.3	How many rooms do you use in the house including kitchens and living rooms in winter? (number of heated rooms)	_______ -98	Number of rooms -98 N/A/ Refuse
2.4	Do you have central heating?	1 2 -98	1 Yes 2 No -98 N/A/ Refuse
2.5	/Ask if 2.4= 2/Does the house have a heating wall? 	1 2 -98	3 Yes 4 No -98 N/A/ Refuse
2.6	/Ask if 2.4= 2/ Is the primary heating stove indoors, or outside the main living area?	1 2 3 4	1. Indoors 2. Separate 3. Other: SPECIFY__________________

2.7	What are the insulation materials of the exterior walls of your house? SELECT ALL THAT IS APPLICABLE (MULTIPLE)	1 2 3 4 5 6 -98 -99	1. None 2. Fiber glass 3. Rock wool 4. Foam 5. Styrofoam (penoplex) 6. Other (Specify) ______________ ______________ -98 N/A/ Refuse -99 Do not know
2.8	What basic material is the floor of your house made of?	1 2 3 -98 -99	1. Wooden boards 2. Cement 3. Linoleum 4. Laminate 5. Other (Please specify) __________ ______________ -98 N/A/ Refuse -99 Don't know
2.9	Do you have additional insulation materials above the ceiling? (Have you additionally insulated the roof of your house?) SELECT ALL THAT IS APPLICABLE (MULTIPLE)	1 2 3 4 5 -98 -99	1. No insulation 2. Fiber glass 3. Rock wool 4. Foam 5. Basalt slabs 6. Other(Specify) ______________ ______________ -98 N/A/ Refuse -99 Don't know
2.10	Are the windows single or double glass? SELECT ALL THAT IS APPLICABLE (MULTIPLE)	1 2 3 -98 -99	Single , wooden window Double, wooden window Single, plastic window Double, plastic window More than three glasses , plastic window Others (Specify) ______________ ______________ -98 N/A/ Refuse -99 Don't know

3.HEATING

3.1 WHAT KIND OF WINTER HEATING DO YOU MAINLY USE? (Select one)

Coal district cooperative heating (central heating)	1
Individual stove and water/ steam heating pipes (household level central heating)	2
Individual stove with chimney (no pipes)	3
Electric radiative heating	4
Electric heat pump	5
Electric floor heating	6
Natural gas district cooperative heating (central heating)	7
Natural gas steam pipe heating (household level central heating)	8
Natural gas stove indoors (no Pipes)	9
Other stove ___________________________________	10

3.2 WHAT KIND OF ADDITIONAL WINTER HEATING DO YOU USE? SELECT ALL THAT IS APPLICABLE (MULTIPLE)

Coal district cooperative heating (central heating)	1
Individual stove and water/ steam heating pipes (household level central heating)	2
Individual stove with chimney (no pipes)	3
Electric radiative heating	4
Electric heat pump	5
Electric floor heating	6
Natural gas district cooperative heating (central heating)	7
Natural gas steam pipe heating (household level central heating)	8
Natural gas stove indoors (no Pipes)	9
Other stove ___________________________________	10
None	11

/ASK IF 3.1 or 3.2 = 2 or 3 / WHAT KIND OF FUEL MATERIALS DO YOU MAINLY USE FOR WINTER HEATING? (Select one) *(Read all options)*		**/ASK according to the answers 3.4.1/Do you buy it?** 1. Yes 2. No -98 N/A / Refuse
3.4.1		**3.4.2**
1	Raw coal	1 2 -98
2	Coal Briquette	1 2 -98
3	Semi coking coal briquette	1 2 -98
4	Tree Trunk Wood	1 2 -98
5	Charcoal	1 2 -98
6	Animal dung	1 2 -98
7	Different types of garbage	1 2 -98
8	Used clothing/textiles	1 2 -98
9	Plastic	1 2 -98
10	Particle board	1 2 -98
11	Worn out car and bicycle tires	1 2 -98
12	Sawdust	1 2 -98
13	Wood/lumber cutoffs	1 2 -98
14	Used building material wood	1 2 -98
15	Others (Specify……………………….)	1 2 -98

/ASK IF 3.1 or 3.2 = 2 or 3 / IF YOU USE AN INDOOR STOVE OR STOVE WITH BOILER, WHAT ADDITIONAL FUEL MATERIALS ARE USED FOR HEATING? SELECT ALL THAT IS APPLICABLE (MULTIPLE) *(Read all option)*		**/ASK according to the answers in 3.5.1/ Use for:** 1. Fuel 2. Light 3. Both -98 N/A/ Refuse	**/ASK according to the answers in 3.5.1/ Do you buy it?** 1. Yes 2. No -98 N/A / Refuse
3.5.1		**3.5.2**	**3.5.3**
1	Raw coal	1 2 3 -98	1 2 -98
2	Coal Briquette	1 2 3 -98	1 2 -98
3	Semi coking coal briquette	1 2 3 -98	1 2 -98
4	Tree Trunk Wood	1 2 3 -98	1 2 -98
5	Charcoal	1 2 3 -98	1 2 -98
6	Animal dung	1 2 3 -98	1 2 -98
7	Different types of garbage	1 2 3 -98	1 2 -98
8	Used clothing/textiles	1 2 3 -98	1 2 -98
9	Plastic	1 2 3 -98	1 2 -98
10	Particle board	1 2 3 -98	1 2 -98
11	Worn out car and bicycle tires	1 2 3 -98	1 2 -98
12	Sawdust	1 2 3 -98	1 2 -98
13	Wood/lumber cutoffs	1 2 3 -98	1 2 -98
14	Used building material wood	1 2 3 -98	1 2 -98
15	Others (Specify……………………….)	1 2 3 -98	1 2 -98
16	none	-98	-98

Note: the 1st stove should be the one used most often.			1st stove	/2nd stove
3.6	Do you use a separate stove for cooking?	1. Yes 2. No -98 N/A -99 Do not know/Refuse	1 2 -98 -99	
3.7	What stove do you mainly use for cooking?	1. Gas stove 2. Electric stove 3. Coal Stove 4. microwave 5. other: specify________________ 6. none -98 N/A/ Refuse -99 Don't know	1 2 3 4 5 6 -98 -99	
3.8	/ASK IF 3.1 or 3.2 = 2, 3 or 9/ What do you use your heating stove for?	1. For heating only 2. For cooking only 3. For both heating and cooking 4. No stove -98 N/A/ Refuse -99 Don't know	1 2 3 4 -98 -99	1 2 3 4 -98 -99
3.9	/ASK IF 3.1 or 3.2 = 2, 3 or 9/ Does your heating pattern change on work day and non-working day?	1. I don't heat on work day 2. I heat less on work days 3. I heat more on work days 4. I heat the same on work and non-working day -99. Don't know 98. Refuse	1 2 3 4 -99	
3.10	/ASK IF 3.1 or 3.2 = 2, 3 or 9/ On a daily basis how many times do you light your stove/turn on heating (maintained heating) during a weekday?	1. No heat 2. Once 3. Twice 4. Three times 5. Four times 6. Constantly on -98 N/A/ Refuse -99 Don't know	1 2 3 4 5 6 -98 -99	
3.11	/ASK IF 3.1 or 3.2 = 2, 3 or 9/ On a daily basis usually how many times do you light your stove/turn on heating during a weekend day?	1. No heat 2. Once 3. Twice 4. Three times 5. Four times 6. Five and more times 7. Constantly on -98 N/A/ Refuse -99 Don't know	1 2 3 4 5 6 -98 -99	

4.FUEL COST

4.1	**/ASK IF 3.4.1 or 3.5.1=1,2 , 3/Where do you usually get your COAL?**	1 2 3 4 -98 -99	1. From a street retail vendor 2. From a coal market 3. Delivery 4. Other(Specify) -98 N/A / Refuse -99 Don't know

/ASK IF 4.1≠4, 98, 99 /

4.3.1	**Fuel type**	**Measure: In what do you buy coal?** 1. Truckload 2. Bucket 3. Sack 4. Weight -98 N/A	**What is the price per measure the coal you bought?** 1. __tons/soms 2. Bucket 3. sack 4. __ tons/soms -98 N/A/ Refuse -99 Don't know	**What is the number of units you bought during last heating period (season)?** 1. __tons/soms 2. Bucket 3. sack 4. __ tons/soms -98 N/A / Refuse -99 Don't know
		4.3.2	**4.3.3**	**4.3.4**
1	/Ask if 3.4.1 or 3.5.1=1 or 3.5.1 =1 /Raw coal		1 2	1 -98 -99
2	/Ask if 3.4.1 or 3.5.1=2 or 3.5.1 =2/Briquette		1 2	1 -98 -99
3	/Ask if 3.4.1 or 3.5.1 =3/Semi coking coal		1 2	1 -98 -99

4.5	**/Ask if 3.4.1 or 3.5.1.=4, 5, 10, 12,13,14 /Where do you usually get your WOOD or CHARCOAL?**	1 2 3 -98 -99	1. From a street retail vendor 2. From a market 3. Collect by themselves 4. Other(Specify) ________________ -98 N/A / Refuse -99 Don't know

4.7.1	**wood type**	**Measure: In what do you buy wood?** 1. Sack 2. bundle 3. bucket 4. weightDo not buy -98 N/A	**What is the price per measure?** 1. Sack 2. bundle 3. bucket___ 4. ___ tons -98 N/A/ Refuse -99 Don't know	**Where did you get your wood on your last purchase?** 1. From a street retail vendor 2. From a wood market 3. Other(Specify) -98 N/A/ Refuse -99 Don't know
		4.7.2	**4.7.3**	**4.7.4**
1	/Ask if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1=4/Split logs			1 2 3 -98 -99
2	/Ask if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1=4/logs			1 2 3 -98 -99
3	/Ask if if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1.=4, 13/Sticks/ branches			1 2 3 -98 -99
4	/Ask if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1.=5/Charcoal			1 2 3 -98 -99
5	/Ask if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1=10/fiberboard			1 2 3 -98 -99
6	/Ask if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1=12/sawdust			1 2 3 -98 -99
7	/Ask if3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1=13/Lumber trimmings			1 2 3 -98 -99
8	/Ask if 3.4.2 or 3.5.3=1 AND 3.4.1 or 3.5.1=, 14,15/Other (Specify)			1 2 3 -98 -99
-99	Don't know	-99	-99	1 2 3 -98 -99

5. RENEWABLE ENERGY

5.1	**Do you use alternative sources of heating, such as solar panels or heat pumps?**	1 2 -99	1. Yes, the solar panels only 2. Yes, heat pumps only 3. Yes, both solar panels and heat pumps 4. No 99 Don't know 98. Refuse
Do you agree with the following statements?			
5.2	**/ASK IF 5.1 = 2 or 4/ I do not have enough knowledge about use of solar panels.**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know - 98 N/A
5.3	**/ASK IF 5.1 = 2 or 4/ The cost of solar panels is too high comparing to traditional energy sources such as electricity and coal.**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know
5.4	**/ASK IF 5.1 = 2 or 4/ I plan to install solar panels in near future.**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know - 98 N/A/ Refuse
5.5	**/ASK IF 5.1 = 1 or 4/ I do not have enough knowledge about use of heat pumps**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know - 98 N/A/ Refuse
5.6	**/ASK IF 5.1 = 1 or 4/ The cost of heat pumps is too high comparing to traditional energy sources such as electricity and coal.**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know - 98 N/A/ Refuse
5.7	**/ASK IF 5.1 = 1 or 4/ If a heat pump provided air conditioning in the summer as well as heating in winter, it would increase my interest in buying it.**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know - 98 N/A/ Refuse

5.8	**/ASK IF 5.1 = 1 or 4/ I would be interested in having an air conditioner in my home**	1 2 3 4 5 6 -98	1. Completely disagree 2. Disagree 3. Neutral 4. Agree 5. Completely agree 99. I don't know - 98 N/A/ Refuse
5.9	**/ASK IF 5.1 = 1 or 4/ I plan to install heat pumps in near future.**	1 2 -99	Yes No -99 Don't know 98. Refuse

6. SMOKING

6.1	**Does anybody smoke inside the house?**	1 2 -99	1. Yes 2. No -99 Don't know/Refuse
6.2	**/ASK IF 6.1=1/How many smokers are there in the household?**	1 2 3 4 -98 -99	Number of people -98 N/A -99 Don't know 98. Refuse
6.3	**/ASK IF 6.1=1/How many cigarettes are smoked per day?**	__ __ -98 -99	Number of Cigarettes -98 N/A -99 Don't know 98. Refuse
6.4	**Does the household have electricity?**	1 2	1. Yes 2. No
6.5	**/ASK IF 6.4=1/Were there power outages during the last week?**	1 2 -99	Yes No -99 Don't know 98. Refuse

6.6	**/ASK IF 6.5=1/ Were outages, how long were the outages?**	Monday 6.6	Tuesday 6.7	Wednesday 6.8	Thursday 6.9	Friday 6.10	Saturday 6.11	Sunday 6.12
6.7	**/ASK IF 6.5=1/ Write number of hours -98 N/A/ Refuse -99 Don't know**	____ -98 -99	____ -98 -99	____ -98 -99	____ -98 -99	____ -98 -99	____ -98 -99	____ -98 -99

7. HOUSEHOLD INCOME

7.1	**What is the approximate average monthly income of your household: the sum of all the money earned and received by all members of your family (in Kyrgyz som)?**	1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. -99.	1. Less than 5 000 som 2. 5 001 – 10 000 som 3. 10 001 – 15 000 som 4. 15 001 – 20 000 som 5. 20 001 – 30 000 som 6. 30 001 – 40 000 som 7. 40 001 – 50 000 som 8. 50 001 – 60 000 som 9. 60 001 – 70 000 som 10. 70 001 – 80 000 som 11. More than 80 001 som -99 Don't know 98. Refuse
7.2	**What is a consumer status of your household?**	1. 2. 3. 4. 5. 6. -98. -99.	1. Sometimes we don't even have enough money for food 2. We have enough money for food, but buying clothes is a serious problem 3. We have enough money for food and clothes, but it would be difficult to buy large household appliances now (refrigerator, washing machine, etc.) 4. We have enough money to buy large household appliances, but we cannot buy a new car 5. Our earnings are enough for everything, except for the purchase of such things as a cottage and an apartment 6. We do not experience financial difficulties, if necessary, we can buy a cottage or an apartment -98 N/A -99 Don't know 98. Refuse
7.3	**Please tell me how much of your total monthly family income your family spends on food and utilities (rent, electricity, gas, phone, etc.)?**	1. 2. 3. 4. -98. -99.	1. Less than a quarter of family income 2. From a quarter to a half of the family income 3. From half to three quarters of the family income 4. More than three quarters of the family income -98 N/A -99 Don't know 98. Refuse

8. HEALTH

8.1	**Do you have a persistent cough or difficulty breathing**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.2	**In last years has any of your family members admitted to the hospital with a respiratory decease, not COVID?**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.3	**Does any of your family members have a persistent cough or difficulty breathing**	1 2 -99	1. Yes 2. No -99 Don't know
8.4	**Do you get out of breath easily climbing stairs**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.5	**Does any of your family members get out of breath easily climbing stairs**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.6	**Do you take prescription medication for lung disease**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.7	**Does any of your family members take prescription medication for lung disease**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.8	**Have you been diagnosed with high blood pressure**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.9	**Does any of your family been diagnosed with high blood pressure members**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.10	**Have you been diagnosed with asthma?**	1 2 -99	Yes No -99 Don't know 98. Refuse
8.11	**/Ask if 1/3_4 ≠0/ Have any of your children been diagnosed with asthma?**	________ -98 -99	Number of children -98 N/A -99 Don't know 98. Refuse

8.12	**Do you feel wintertime air pollution does you any harm?**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.13	**Do you try to stay inside when there are high levels of air pollution?**	1 2 -99	1. Yes 2. No -99 Don't know 98. Refuse
8.14	**Do you try to keep your children inside when there are high levels of air pollution?**	1 2 -98 -99	1. Yes 2. No -98 N/A -99 Don't know 98. Refuse
8.15	**On a scale of 0 to 5 do you feel high levels of air pollution affects your breathing?**	0 1 2 3 4 5 -99	1. Not at all/don't feel anything 2. Feel very little/almost imperceptible 3. Feel something but not much 4. Feel a little tightness in chest 5. Feel some tightness in chest 6. Feel shortness of breath -99 Don't know 98. Refuse

APPENDIX 6: CONTINGENT VALUATION SURVEY

Hypothetical Question.

You were randomly selected to participate in a survey conducted by M-Vector on behalf of the United Nations Children's Fund (UNICEF) Office in the Kyrgyz Republic. The goals of the project are to see how people living in Bishkek value longer lifespan with fewer sick days. This questionnaire contains several scenarios that you need to imagine. These imaginary scenarios are followed by a few questions that ask how much people value certain actions that reduce sick days and increase life expectancy. We are not trying to sell you anything, and answering will not result in you having to pay anything, nor will there be anybody in the future coming to ask you to pay as a result of answering these questions. We just want to understand how people value their additional life expectancy and increase in its quality.

All information and opinions you share are anonymous. Your name will not be recorded or used in any document developed based on the results of the study. If you have any questions regarding this study, please contact Beishekeeva Aida at the following email address aida.beishekeeva@m-vector.com

1. Household income

7.1	What is the approximate average monthly income of your household: the sum of all the money earned and received by all members of your family (in Kyrgyz som)?	1. 2.	1. Less than 5 000 som 2. 5 001 – 10 000 som	BID group 1
		3. 4.	3. 10 001 – 15 000 som 4. 15 001 – 20 000 som	Bid group 2
		5. 6.	5. 20 001 – 30 000 som 6. 30 001 – 40 000 som	BID group 3
		7. 8.	7. 40 001 – 50 000 som 8. 50 001 – 60 000 som	BID group 4
		9. 10. 11.	9. 60 001 – 70 000 som 10. 70 001 – 80 000 som 11. More than 80 001 som	BID group 5
		-99.	-99 Don't know/Refuse	

	Bid group 1			Bid group 2			Bid group 3		
Income - Som/month	0-10,000			10,001-20,000			20,001 - 40000		
	BID	BID HIGH	BID LOW	BID	BID HIGH	BID LOW	BID	BID HIGH	BID LOW
Row 1	2000	3000	1000	4000	6000	2000	7000	10000	4000
Row 2	4000	6000	2000	5000	7000	3000	10000	14000	6000
Row 3	6000	8000	4000	7000	9000	5000	14000	18000	10000
Row 4	8000	10000	6000	10000	13000	7000	19000	23000	15000
Row 5	10000	12000	8000	13000	17000	9000	24000	29000	19000

	Bid group4			Bid Group 5		
Income - Som/month	40,001-60,000			Income >60,000		
	BID	BID HIGH	BID LOW	BID	BID HIGH	BID LOW
Row 1	11000	16000	6000	14000	20000	8000
Row 2	14000	18000	10000	19000	25000	13000
Row 3	22000	28000	16000	28000	36000	20000
Row 4	29000	35000	23000	37000	45000	29000
Row 5	36000	44000	28000	47000	57000	37000

I am now going to present you with two hypothetical scenarios followed by several questions which ask how much you value the benefits (in this case, an increase in life expectancy), which can be provided to you if you perform certain actions. These are made up scenarios and no payments are required now, or in the future. ***Please imagine the following scenarios, however, as if you were actually in the situation presented***

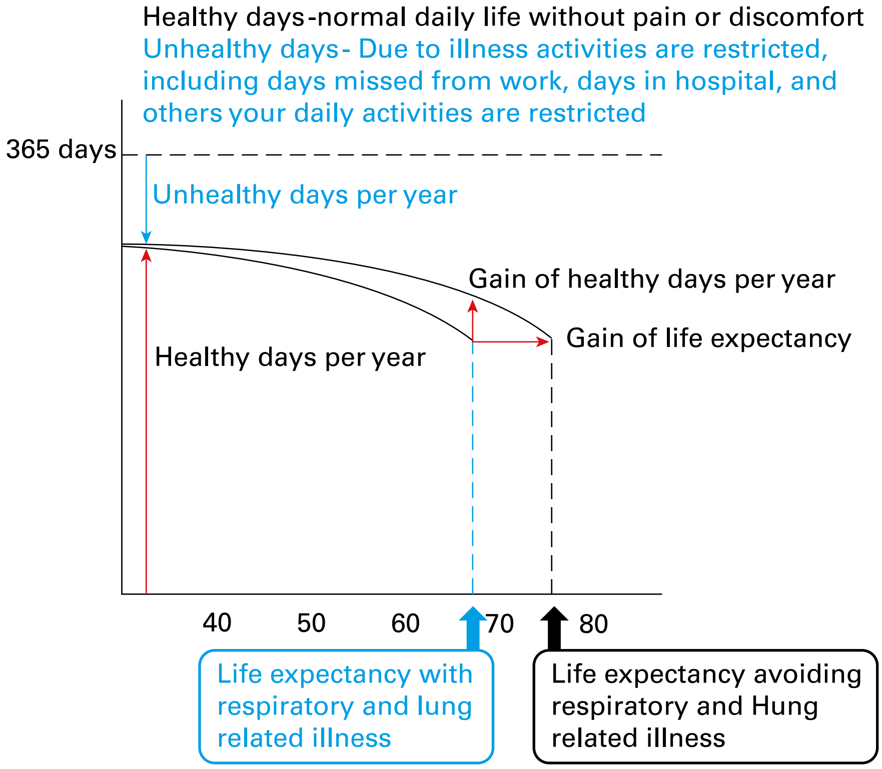
Let's now consider the effect of health on life expectancy. Life expectancy is the number of years on average you can expect to live, depending on how old you are now. For example, at the beginning of their lives a baby girl in Bishkek has an average life expectancy of 75 years, and a baby boy has an average life expectancy of 68 years.

IF THE RESPONDENT IS A MAN, THEN CHOOSE AN APPROXIMATE APPROPRIATE AGE AND READ:

-If you are 20 years old, you expect to live on average for another 48 years
-If you are 35 years old or more, then on average you can still live for 33 years
-If you are about 50, then on average you can live for about 18 more years.
IF THE RESPONDENT IS A WOMAN, THEN CHOOSE THE APPROPRIATE AGE AND READ:

-If you are 20 years old, you expect to live on average another 55 years
-If you are 35 years old or more, then on average you can still live 40 years,
-If you are about 50, then on average you can live about 25 more years.
Better health status will increase the number of days per year that you are not sick, and can result in a gain in life expectancy since better health status will slow down your aging process.

Life expectancy in Bishkek.

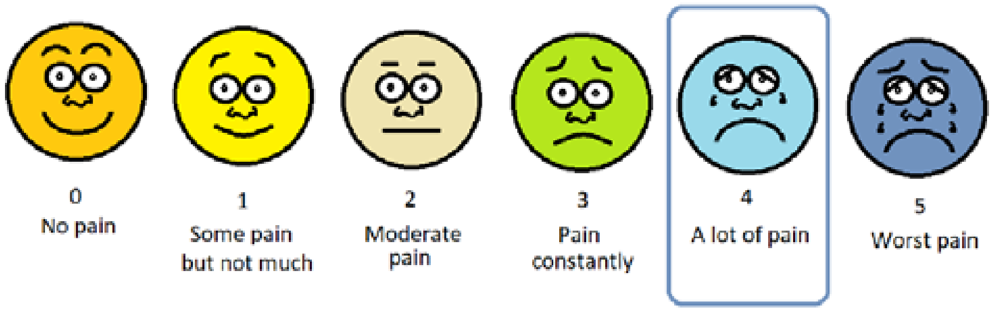


Experiencing a disease like chronic bronchitis and lung related illness can increase the number of days you are sick per year and decrease the overall number of years you can expect to live on average.

For example, the major symptoms of chronic bronchitis include:

(i) intensive coughing that lasts for 3 months or more per year,
(ii) wheezing,
(iii) shortness of breath,
(iv) production of sputum with yellow or green color with small amount of blood.

These symptoms are caused by the irritation to the lungs. Chronic bronchitis may cause you to be hospitalized, visit emergency room or doctors. You may need to take days off from your work, which may cause you to lose some part of your income. When the symptoms are severe, your daily activities are also restricted. Imagine the level of pain and discomfort is "4" in the pain scale.



Suppose that if you have ongoing lung and bronchial diseases which mean you cannot go to work and need you go to hospital for an average of 10 days each year after you are 60 years old, then the amount you spend on medical co-payments for medication, diagnostics, hospitalization cost and specialist visits in the Kyrgyz Republic is 18,880 SOM as an out-of-pocket treatment cost, not including the amount of income you may lose as a result of not working for 10 days.

Now suppose if you spend a certain amount of money, for example, on maintaining a healthy lifestyle, proper nutrition, scheduled visits to doctors, the use of preventive medicine, changing your place of residence to a more environmentally friendly area, you can avoid the occurrence of respiratory and lung related illnesses in your life such as pneumonia, chronic bronchitis, and asthma. The avoidance of these illnesses will gain you 10 more healthy days each year after age 60 and you will have [Version 1: 2 more years, Version 2: 5 more years] added to your average life expectancy. Remember we are interested in how you value these benefits, and that these are made up scenarios and answering these questions will not result in you having to pay anything.

Q1.	What is your opinion on the gains of healthy days each year and extended life expectancy	1. Significantly positive 2. Positive 3. Neutral 4. Negative 5. Significantly negative 6. Don't know

Q2.	Would you pay for improving the quality of health and life or spending money on maintaining a healthy lifestyle, proper nutrition, scheduled visits to doctors and the use of preventive medicine, the use of vitamins) [INSERT BID] SOM every year for the rest of your life to avoid the respiratory and lung related illnesses entirely, gain the number of healthy days each year, and add [Version 1: 2 more years, Version 2: 5 more years] to your normal life expectancy? Please remember that if you agree to pay, you may have to give up some of the planned expenditure for the goods such as a good television, a smart phone or a computer. Note: if the respondent asks why this particular amount comes out, it is necessary to explain that, based on the level of household income, a random number appears that are offered to be paid or spent.	1. Yes 2. No 3. Decline to answer- GO TO Q4
Q3	Would you pay for improving the quality of health and life or spending money on maintaining a healthy lifestyle, proper nutrition, scheduled visits to doctors and the use of preventive medicine, the use of vitamins)) [INSERT BID] SOM every year for the rest of your life to avoid the respiratory and lung related illnesses entirely, gain the number of healthy days each year, and add [Version 1: 2 more years, Version 2: 5 more years] to your normal life expectancy? Note: if the respondent asks why this particular amount comes out, it is necessary to explain that, based on the level of household income, a random number appears that are offered to be paid or spent.	1. Yes 2. No 3. Decline to answer- GO TO Q4
Q4	If you answered no to Q2 and Q3. Please explain the reasons for your answers	1. Budget constraints 2. Scenarios are not realistic 3. I did not understand the scenario well 4. It's not my responsibility 5. Other; Specify ____________

Now suppose breathing air pollution and coal smoke causes chronic bronchitis and lung related illness, and can increase the number of days you are sick and decrease the number of years you can expect to live on average. In order to increase the number of healthy days each year and decrease the risk of experiencing a disease like chronic bronchitis and lung related illness, there are certain things you can do to reduce the amount of air pollution and coal smoke you breathe. For example, switching from coal-based heating stove to gas or central heating system, using electricity for heating, or using an air-purifier at home are among the things you can do for a healthier and longer life.

Now suppose if you spend a certain amount of money per year for household improvements (switching from coal-based heating stove to gas or central heating system, using electricity for heating, or using an air-purifier at home), you can avoid the occurrence of respiratory and lung related illnesses in your life such as pneumonia, chronic bronchitis, and asthma. The avoidance of these illnesses will gain you 10 more healthy days each year after age 60 and you will have [Version 1: 2 more years, Version 2: 5 more years] added to your average life expectancy in the end of your life.

Q5.	What is your opinion on the gains of healthy days each year and extended life expectancy	1. Significantly positive 2. Positive 3. Neutral 4. Negative 5. Significantly negative 6. Don't know
Q6.	Would you pay or spend on these improvements in everyday life (switching from a coal-fired heating stove to a gas or central heating system, using electricity for heating or using an air purifier at home [INSERT BID] SUM every year for the rest of your life to avoid the respiratory and lung related illnesses entirely, gain the number of healthy days each year, and add [Version 1: 2 more years, Version 2: 5 more years] to your normal life expectancy? Please remember that if you agree to pay, you may have to give up some of the planned expenditure for the goods such as a good television, a smart phone or a computer. Note: if the respondent asks why this particular amount comes out, it is necessary to explain that, based on the level of household income, a random number appears that are offered to be paid or spent.	1. Yes 2. No 3. Decline to answer- GO TO Q8
Q7	Would you pay or spend on these improvements in everyday life (switching from a coal-fired heating stove to a gas or central heating system, using electricity for heating or using an air purifier at home [INSERT BID] SUM every year for the rest of your life to avoid the respiratory and lung related illnesses entirely, gain the number of healthy days each year, and add [Version 1: 2 more years, Version 2: 5 more years] to your normal life expectancy? Note: if the respondent asks why this particular amount comes out, it is necessary to explain that, based on the level of household income, a random number appears that are offered to be paid or spent.	1. Yes 2. No 3. Decline to answer- GO TO Q8
Q8	If you answered no to Q6 and Q7. Please explain the reasons for your answers	1. Budget constraints

		2. Scenarios are not realistic 3. I did not understand the scenario well 4. It's not my responsibility 5. Other; Specify ____________________

APPENDIX 7: HEALTH IMPACTS OF AIR POLLUTION

The following sections summarize health impacts as a result of exposure to air pollution and are drawn in large part directly from the UNICEF publication "Understanding and Addressing the Impact of Air Pollution on Children's Health in Mongolia." [51], and the ADB/UNICEF report "Reducing impacts of prenatal and early life exposures to air pollution"[52]. They are reproduced here as a reference for some of the compelling scientific evidence on the consequences of prenatal and early life exposures to the high levels of air pollution currently experienced in Bishkek. The health impacts identified are also supported by the World Health Organization report "Air pollution and child health: prescribing clean air" [53].

1. AIR POLLUTION-RELATED MORTALITY

The effects of long term exposure to air pollution on cardiovascular morbidity and mortality are well documented[54]. Exposure to $PM_{2.5}$ over a few hours to weeks can trigger cardiovascular disease-related mortality and nonfatal events; longer-term exposures increase the risk for cardiovascular mortality and reduce life expectancy within more highly exposed segments of the population by several months to a few years, with credible pathological mechanisms[54]. More importantly, reductions in PM levels show near-immediate benefits with decreases in cardiovascular mortality within time frames as short as a few years[54].

Large cohort studies have investigated the relationship between long-term exposures to $PM_{2.5}$ and ozone and mortality[55], including at concentrations lower than current US standards[56]. There is good evidence that major health impacts persist at levels lower than WHO air quality guidelines, which reinforces the need to reduce air pollution to very low levels to achieve major health benefits. More recently, a nationwide cohort study involving all Medicare beneficiaries from 2000 through 2012, a population of 61 million, was investigated to provide information on the health effects of long-term exposure to low levels of $PM_{2.5}$ air pollution across the population, including among minorities or persons with low socioeconomic status in smaller cities and rural areas[57].

Increased risks in all-cause mortality of 7.3 per cent (95 per cent CI 7.1-7.5) in this nationwide cohort were associated with increases of 10 $\mu g/m^3$ in annual average ambient $PM_{2.5}$ concentrations, with increased risks when the population was constrained to those exposed to concentrations less than the US national standard of 12 $\mu g/m^3$.[57]

Both short and long term exposures to particulate matter are associated with increased risk for cardiovascular events and hospital admissions for pneumonia[58,59]. However, exposure-response estimates for chronic health impacts of air pollution in the global burden of disease estimates are based on long term averages of air pollution exposure. Although peak exposures may play a role in health impacts, there is currently insufficient evidence to characterize these impacts.

2. AIR POLLUTION AND LUNG FUNCTION

Effects of air pollution on lung function in children can occur even at lower levels of exposure, as children's lungs are still maturing and therefore especially vulnerable to pollution. Compromised lung function in children is associated with long-lasting chronic conditions such as asthma and chronic obstructive pulmonary disease, and prenatal exposure to air pollution can predispose individuals to cardiovascular disease later in life53. In contrast, long-term improvements in air quality were associated with statistically and clinically significant positive effects on lung-function growth in children[60].

Exposure to air pollution in children results in a large direct burden of disease due to ALRI, which in turn may increase susceptibility to chronic air pollution related disease. For example, both non-severe and severe pneumonia increased the risk of at least one long-term major chronic condition, most commonly reduction in lung function, as a result[61]. In addition, air pollution exposures and repeated incidence of pneumonia in children are both linked to increased incidence of chronic air pollution-related disease later in life[62].

The time periods of vulnerability for these critical outcomes are different, however, with the vast majority of ALRI resulting from risk factors and exposures that act during the period from pre-pregnancy to two years old, with the most critical windows for air pollution and infection in the first two or three months of life. In contrast, air pollution exposures that lead to later chronic respiratory disease may affect lung development throughout development, with critical periods of vulnerability reflecting time periods for organ development and maturity. Structure and function of the lungs are permanently altered in their design by factors operating during sensitive periods of fetal or early post-natal life[63]. Much of the lung disease development in prenatal and maternal prenatal smoking and passive maternal prenatal smoking have been extensively studied and are associated with irreversible alterations in lung growth[63, 64].

After birth, infants and toddlers ventilate with flaccid ribcage with less effective ventilation, less effective diaphragm, and lowered functional residual capacity. Alveolar development is completed by age three, after which growth occurs mainly by enlargement. There is a gradual increase in thoracic stiffness and lung compliance. It continues during childhood and results in an under distension of the lungs below the age of seven to eight and an over distension above this age[63]. The factors that adversely affect the growth of the respiratory system has been covered elsewhere in much more detail.[65] However, of particular relevance is that the development of children's lungs occurs throughout childhood, and measures should be taken at all stages to reduce children's exposure to air pollution.

Clearly, a priority is to reduce exposure in residential environments during early development to reduce pneumonia and lung development impacts; however, measures should also be taken to reduce air pollution exposures in school-age children to reduce impacts of air pollution-related diseases later in life.

3. AIR POLLUTION AND PNEUMONIA

For children, pneumonia as acute lower respiratory infections contributes to the vast majority of the health burden from air pollution related disease in children. Children exposures to air pollution, however, may contribute to the incidence of chronic air pollution related disease later in life. For example, structural remodelling as a result of respiratory disease that interferes with the growth of air passages at crucial time periods may have long term effects on respiratory health, and there is little evidence of catch up afterward[66].

In 2017, twenty-two per cent of all deaths in children under five years were estimated to be due to acute lower respiratory tract infections (ALRI), with thirty-six per cent attributable to particulate matter pollution[67]. Causes of life-threatening invasive bacterial infections in the neonatal period are uncertain as infections might be environmentally acquired rather than perinatally acquired. However, in the late neonatal and postneonatal periods, Gram-positive cocci (primarily Streptococcus spp) cause about two of every three infections. As children grow older, the causes of clinical pneumonia are mainly respiratory syncytial virus, influenza virus, Streptococcus pneumoniae, and Haemophilus influenzae. Although ninety-five per cent of all deaths from ALRIs occur in low and middle-income countries[68], a meta-analysis of ten European birth cohorts (ESCAPE study) found a significant association between air pollution and pneumonia[69]. Eighty-one per cent of the deaths from pneumonia occur in the first two years of life[70], and socioeconomic and environmental factors also contribute through air pollution, young maternal age, low maternal education, and environmental tobacco smoke exposure[68]. Recent exposure to second-hand cigarette smoke has been shown to be associated with increased severity of lower respiratory tract infections due to respiratory syncytial virus (RSV) in hospitalised children aged under one year[71]. Exposure to tobacco smoke increases Streptococcus pneumoniae nasopharyngeal carriage rates in children [72], which can act both as a disease precursor and mode of transmission between individuals. Furthermore compromised host immune responses in the nasopharynx following cigarette smoke exposure predispose individuals to invasive pneumococcal disease[73].

Respiratory syncytial virus (RSV) infection is the major global cause of ALRI. In South Africa, viral pathogens were found in seventy-eight per cent of children under one year of age with ALRI[74], and eighty per cent of children at two years of age have been infected with RSV. One-third of them will have developed an ALRI, usually bronchiolitis (inflammation of the small airways in the lung)[75]. Major risk factors for severe RSV leading to hospitalization include lower gestational age, under three months of age at the onset of RSV season, and living with school-age siblings. Lack of breastfeeding, and nutrition did not appear to increase the risk of severe RSV infection[76].

Important vaccine-preventable causes of severe pneumonia are S pneumoniae (which causes at least eighteen per cent of severe episodes and thirty-three per cent of deaths worldwide), the influenza virus (seven per cent of severe episodes and eleven per cent of deaths), and H influenzae type b (four per cent of severe episodes and sixteen per cent of deaths)[70]. The effects of air pollution are more pronounced for bacterial causes of pneumonia compared to RSV[77], although there is evidence for a role of viral pathogens in bacterial pneumonia[78].

4. HEALTH IMPACTS FROM PRENATAL AND EARLY LIFE EXPOSURES

Cognitive development

Brain development comprises an array of qualitatively different processes with overlapping timing: neural tube formation, cell proliferation and differentiation, migration, dendritic arborisation, synaptogenesis, apoptosis, formation, and connectivity of cortical mini-columns, and myelination[79]. Neurogenesis takes place at an astonishing rate, averaging 250,000 new neurons per minute during gestation; the result is 100 billion neurons at birth[80]. Most of the growth is in the third trimester when 40,000 synapses are formed per minute. This high growth rate is vulnerable to environmental insults and the prenatal and early postnatal periods are the most vulnerable window[81]. Long-term exposure to particulate air pollution levels typical of exposure in major cities around the globe can alter neurological responses and impair cognition[82]. Disorders of neurobehavioral development affect ten to fifteen per cent of all U.S. births[83]. Subclinical decrements in brain function are even more common than these neurobehavioral developmental disorders, which can have severe consequences for the welfare and productivity of entire societies[84]

Executive processes develop throughout childhood and adolescence and play an important role in a child's cognitive functioning, behaviour, emotional control, and social interaction. High cognitive executive functions essential for learning[85] develop significantly from six to ten years of age[86]. Attentional control appears to emerge in infancy and develop rapidly in early childhood, whereas cognitive flexibility, goal setting, and information processing have a critical period of development between seven and nine years of age, and are relatively mature by twelve years of age.[86]

The neural systems responsible for executive functioning are numerous, complex and inter-related with the prefrontal cortex dependent on efferent and afferent connections with virtually all other brain regions including the brain stem, occipital, temporal, and parietal lobes, as well as limbic and subcortical regions[87]. Damage or loss of function at any level of one of these neural systems may result in cognitive and/or behavioural deficits[86]. Air pollution particles are not restricted to the lungs[88]. Nano-sized particulate matter has been observed in the human brain in highly exposed subjects confirming that air pollution components reach the brain[89, 90]. Inhaled ultra-fine particles (UFP) are efficiently deposited on the olfactory mucosa of the nasal region and will translocate along the olfactory nerve into the brain in rats[91], and evidence from a number of animal models that showed intranasal instilled solid UFP translocate along axons of the olfactory nerve into the brain[91]. In addition, long term chronic exposure to air pollution may cause disruption of the blood-brain barrier[89]. Once in the brain, particulate matter is pro-inflammatory in microglia[92], which may result in chronic inflammation, oxidative stress, neurotoxicity, and cerebral vascular damage. Also, some adsorbed compounds are soluble and may become a toxic stimulus independent of the particle itself[88].

Air pollution exposure results in developmental neurotoxicant effects in the brain of humans and animals[81]. In animals, inhalation of diesel exhaust and ultrafine particles results in elevated cytokine expression and oxidative stress in the brain[93, 94] and altered animal behaviour[82, 95]. The prefrontal cortex and striatum, implicated in executive functions such as working memory and attention[96], have shown inflammatory responses after traffic-related air pollution exposure[93, 97]. In children, numerous studies have shown exposure to traffic-related air pollutants during pregnancy or infancy, when the brain neocortex rapidly develops, has been related to cognitive delays[98, 99, 100], even at low exposure levels[101], which can be modulated by antioxidant intake[100]. Children and dogs exposed to high concentrations of air pollution in Mexico City revealed structural damage in MRI analyses localized to the prefrontal cortex, which may be related to reduced cognitive function[102].

Children spend a large proportion of their day at school, including the period when daily traffic pollution peaks. Many schools are located in close proximity to busy roads. They may be heated in winter with heat only boilers that emit directly in the vicinity of the playground, which increases the concentrations of air pollution around and in schools. In a prospective cohort study of the association between traffic-related air pollution in schools and cognitive development in primary school children in thirty-nine schools in Barcelona, Spain, Children from highly polluted schools had a smaller growth in cognitive development than children from the paired lower polluted schools[98]. Children attending schools with higher levels of EC, NO2, and UFP both indoors and outdoors experienced substantially smaller growth in all the cognitive measurements: working memory (two-back detectability), superior working memory (three-back detectability), and inattentiveness (hit reaction time standard error[98]. Moreover, increased air pollution increases school absenteeism[103], and decreases performance in examinations[104]. In a Guatemala, stove intervention trial CO exposure of pregnant mothers during their third trimesters was associated with impaired child neuropsychological performance on four out of eleven neuropsychological tests including visuospatial integration, short-term memory recall, long-term memory recall, and fine motor performance[105]. Prenatal air pollution exposure could carry long-term consequences such as decreased performance in school, lower educational attainment, and reduced earnings[106].

In New York, high prenatal exposure to Polycyclic aromatic hydrocarbons (PAHs) may adversely affect children's cognitive development at three years of age and odds of cognitive developmental delay[107], with implications for school performance. Numerous studies have shown in utero exposure to ambient air pollution increased risks of autism in children e.g.[108]

Thus pathways linking exposure to air pollution and brain damage include a systemic inflammatory response from particulate resulting in disruption of the nasal and olfactory barriers and the blood-brain barrier, which serves to increase particulate matter uptake, combined with particulate matter uptake through olfactory neurons, cranial nerves such as the trigeminal and vagus, and the systemic circulation. Once in the brain, particulate matter exposure results in expression of inflammatory mediators at low levels and the formation of reactive oxygen species which result in altered neuronal development and damage.

Adverse birth effects

Maternal exposure to air pollution is associated with stillbirth, preterm birth, low birth weight and being small for gestational age[53]. Recent systematic reviews have found exposure to $PM_{2.5}$ was associated with preterm birth, low birth weight and being small for gestational age[109, 110.] Further, there is increased likelihood of preterm birth among women exposed to $PM_{2.5}$ during pregnancy with pre-existing diabetes 10.6 per cent (95 per cent CI:0.2–2.1 per cent) compared to 3.8 per cent (95 per cent CI:2.2–5.4 per cent) among women without this condition[111].

Similarly, there is increased likelihood of preterm birth among women exposed to $PM_{2.5}$ during pregnancy with pre-eclampsia (8.3 per cent, 95per cent CI:0.8–16.4 per cent) compared to women without this condition (3.6 per cent,95 per cent CI:1.8–5.3 per cent)[111]. In a prospective cohort study in China, there was a three per cent (OR = 1.03; 95 per cent CI: 1.02, 1.05) increase in the risk of preterm birth with each 5 μg/m^3 increase in $PM_{2.5}$ with the strongest effect in the second trimester[112].

In a recent systematic review in China sulphur dioxide was more consistently associated with lower birth weight and preterm birth[113], reflecting the use of high sulphur coal for residential heating. In industrialized countries like Canada, which do not have residential coal smoke, traffic is an important predictor of adverse birth effects[114]. Effect estimates for decreased birth weight were generally largest for entire pregnancy exposure, with pooled estimates of decrease in birth weight from 10 μg/m^3 $PM_{2.5}$ exposure of -23.4g (-45.5, -1.4), and pooled odds ratios of 1.05 (0.99–1.12) per 10 μg/m^3 $PM_{2.5}$ based on entire pregnancy exposure[110]. In London, only $PM_{2.5}$ traffic exhaust and $PM_{2.5}$ were consistently associated with increased risk of low birth weight after adjustment for each of the other air pollutants, and three per cent of low birth weight cases were estimated to be directly attributable to residential exposure to $PM_{2.5}$ under 13.8 μg/m^3 during pregnancy[115].

There is also suggestive evidence of associations between exposure to AAP and the incidence of infertility and endometriosis[53]. In China, there was also some evidence for congenital cardiovascular defects[113, 116].

5. AIR POLLUTION AND NEURODEGENERATIVE DISEASE

Inflammatory effects of air pollution may accumulate across an individual's lifespan resulting in neurodegenerative disease[97, 117]. Diffuse neuroinflammation, neurovascular damage, and production of autoantibodies to neural and tight-junction proteins seen in children chronically exposed to ozone and $PM_{2.5}$ air pollution may constitute significant risk factors for the development of Alzheimer's disease later in life[118]. Acute and chronic low-level exposures to ozone (O3) and PM have also demonstrated neurotoxic effects in different animal models[119]. Neuropathological evidence of accelerated brain ageing has been described in the olfactory and respiratory nasal mucosae, olfactory bulb, and cortex of experimental dogs raised in Mexico City[102]. Furthermore, air pollution may cause cardiovascular disease, which is also known to impact cognitive function in later years[120].

A study linking fifteen years of Medicare records for 6.9 million adults age sixty-five and older with cumulative residential exposure to $PM_{2.5}$ with 1 μg/m^3 $PM_{2.5}$ increase in average decadal exposure to $PM_{2.5}$, showed the increasing probability of receiving a dementia diagnosis by 1.3 percentage points, and that the effect of $PM_{2.5}$ on dementia persists below current regulatory thresholds[121]. In a nationally representative longitudinal survey matched with air quality data in China, long-term exposure to air pollution impeded cognitive performance in verbal and math tests[122]. The effect of air pollution on verbal tests becomes more pronounced as people age, especially for men and the less educated. The damage on the ageing brain by air pollution likely imposes substantial health and economic costs, considering that cognitive functioning is critical for the elderly for both running daily errands and making high-stake decisions[122].

In a population-based cohort of 2.2 million adults aged fifty-five to eighty-five years who resided in Ontario, Canada, residential proximity to major roadways was associated with a higher incidence of dementia[123]. Similarly, ambient traffic-related air pollution was associated with decreased cognitive function in older men on a battery of seven cognitive tests[124]. Lung function is also a predictor for cognitive decline in the elderly; however, air pollution and lung function are independent predictors of cognitive decline in the elderly[125].

6. BENEFITS OF EXCLUSIVE BREASTFEEDING

Reduction in health impacts of air pollution related disease can be achieved by the decrease in other child child-specific risk factors. Sub-optimal breastfeeding is a risk factor for pneumonia as exclusive breastfeeding allows maternal IgG antibodies against RSV to cross the placenta with sufficient levels help to protect the infant from severe infection. Exclusive breastfeeding has the single largest potential impact on child mortality of any preventive intervention feasible for delivery at high coverage in low-income settings and is a primary intervention for the prevention of pneumonia[126]. Maternal IgG antibodies against RSV cross the placenta with sufficient levels help to protect the infant from severe infection.

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