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# Impact of particulate matter on the morbidity and mortality and its assessment of economic costs

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**Abstract.** Kazakhstan's cities experience high concentrations levels of atmospheric particulate matter (PM), which is well-known for its highly detrimental effect on the human health. A further increase in PM concentrations in the future could lead to a higher air pollution-caused morbidity and mortality, causing an increase in healthcare expenditures by the government. However, to prevent elevated PM concentrations in the future, more stringent standards could be implemented by lowering current maximum allowable PM concentration limit to Organization for Economic Co-operation and Development (OECD)'s limits. Therefore, this study aims to find out what impact this change in environmental policy towards PM has on state economy in the long run. Future $PM_{10}$ and $PM_{2.5}$ concentrations were estimated using multiple linear regression based on gross regional product (GRP) and population growth parameters. Dose-response model was based on World Health Organization's approach for the identification of mortality, morbidity and healthcare costs due to air pollution. Analysis of concentrations revealed that only 6 out of 21 cities of Kazakhstan did not exceed the EU limit on $PM_{10}$ concentration. Changing environmental standards resulted in the 71.7% decrease in mortality and 77% decrease in morbidity cases in all cities compared to the case without changes in environmental policy. Moreover, the cost of morbidity and mortality associated with air pollution decreased by $669 million in 2030 and $2183 million in 2050 in case of implementation of OECD standards. Thus, changing environmental regulations will be beneficial in terms of both of mortality reduction and state budget saving.

**Keywords**: air pollution; Kazakhstan; mortality and morbidity; healthcare cost; environmental policy

## 1. Introduction

Airborne particulate matter (PM), one of the main indicators of air pollution, consists of various solid and liquid particles such as elemental and organic carbon, nitrates, sulfates, organic compounds, biological compounds (e.g., endotoxin, cell fragments) and various metals (copper, zinc, iron, nickel and vanadium), which are suspended in the air. Particles can combine and form heterogeneous mixtures of various sizes ($PM_{2.5}$ – with a diameter smaller than 2.5 μm; $PM_{10}$ – with

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diameter of 2.5 – 10 μm) and chemical composition (Kim *et al*. 2015). PM draws the attention of the experts worldwide because of its adverse effect on human health (Chiang *et al*. 2016, Li and Lin 2014). Potential health risks due to exposure to PM is directly related to its particle size. Recent research conducted by Jiang *et al*. (2018) evaluated health risk from collected PM in Zhengzhou, China. The study elucidated that crustal elements are mainly found in $PM_{2.5-10}$, while elements generated by anthropogenic sources (e.g., Pb, Zn, As, Cu, Cd, etc.) mainly exist in fine particles rather than in coarse particles (Jiang *et al*. 2018). The study conducted by Dappe *et al*. (2018) also evidences that finest fraction of PMs are the most Pd enriched particles collected from lead recycling plan, suggesting that smaller sized particles are more enriched with elements from anthropogenic sources. PM in the atmosphere could lead to a more dangerous human health consequence compared to other common air pollutants such as carbon monoxide or ground-level ozone (Kim *et al*. 2015). $PM_{10}$ and $PM_{2.5}$ coming from oil refineries results in a health effects such as impaired lungs function, aggravates asthma, respiratory diseases, heart attacks. Also, long-term and short-term exposure causes mortalities associated with chronic obstructive pulmonary disease (COPD) and ischemic heart disease (IHD) in population older than 30 years old (Amoatey *et al*. 2019). A systematic review by Yang *et al*. (2019) concludes that black carbon and organic carbon along with nitrate, sulfate, ammonium, Fe, Si, V and Zn on a surface of $PM_{2.5}$ cause adverse health effects. Epidemiologic studies have revealed a strong positive correlation between the level of $PM_{10}$ and numbers of hospital admissions due to respiratory and cardiovascular disorders all over the world (Anderson *et al*. 1997, Burnett *et al*. 1999, Pope *et al*. 1995, Zanobetti *et al*. 2000). Major negative effects of exposure to $PM_{2.5}$ include irritation of the lung airways, difficult breath, or coughing and premature death due to heart or lung disease, irregular heartbeat, decreased lung function and nonfatal heart attacks (Correia *et al*. 2015, Atkinson *et al*. 2010, Cadelis *et al*. 2014, Fang *et al*. 2013, Meister *et al*. 2012). Air pollution directly increases in the number of deaths by more than two million each year globally due to the negative effect on the lungs and the respiratory system (Shah *et al*. 2013). Among those deaths, cases related to death caused by $PM_{2.5}$ are around 2.1 million (Chuang *et al*. 2011, Shah *et al*. 2013).

The exposure to PM of various particle sizes can lead to a wide range of human health disorders, which in turn cause economical losses. Adverse health effects are associated with additional health expenditure, labor productivity loss, and work time loss and consequently could lead to a significant impact on the economy (Wu *et al*. 2017). Previous scientific works successfully quantified the economic impact due to exposure to outdoor air pollution (Hunt *et al*. 2016). For example, according to the study conducted in the United States, the productivity of agricultural workers was significantly influenced by the ozone levels which were not in the range of federal air-quality standards (Graff Zivin and Neidell 2011). Also, a study conducted in Mexico City states that work hours per week were increased by 1.3 h (3.5%) when $SO_2$ levels were decreased by 19.7% (Hanna and Oliva 2015). In China, air pollution leads to economic losses equal to 0.72-6.94% of the regional GDP of the cities and provinces (Huang and Zhang 2013, Huang *et al*. 2012, Kan and Chen 2004, Wenbo and Shiqiu 2010, Zhang *et al*. 2010). In 2005, global welfare loss due to outdoor air pollution was more than \$5 trillion, including \$1.7 trillion in OECD countries, \$0.5 trillion in India, and \$1.4 trillion in China (OECD 2014). According to OECD's computable general equilibrium model ENV-Linkages, the estimated effect of outdoor air pollution will lead to economic losses equal to 1% of global GDP by 2060 (OECD 2016). In this regard, it is necessary to thoroughly elucidate the effect of outdoor air pollution on health and its economic impact.

Kazakhstan is ninth largest country by area in the world and the second largest residential coal

Table 1 Calculated average annual concentration of $PM_{10}$ for all cities of Kazakhstan in 2011-2017, µg/m$^3$ (Kazhydromet 2018)

| Cities/year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Nur-Sultan | 81 | 80 | 82 | 71 | 99 | 180 | 135 |
| Zhezkazgan | 131 | 129 | 137 | 148 | 127 | 135 | 144 |
| Temirtau | 129 | 107 | 95 | 135 | 136 | 135 | 122 |
| Shymkent | 112 | 94 | 103 | 108 | 105 | 90 | 115 |
| Balkhash | 68 | 78 | 79 | 91 | 91 | 90 | 79 |
| Almaty | 60 | 73 | 52 | 63 | 80 | 90 | 77 |
| Aktau | 106 | 119 | 126 | 105 | 83 | 45 | 95 |
| Atyrau | 83 | 296 | 197 | 110 | 85 | 45 | 62 |
| Taraz | 47 | 141 | 159 | 47 | 45 | 100 | 40 |
| Pavlodar | 92 | 91 | 82 | 80 | 99 | 45 | 41 |
| Ekibastuz | N/A | 29 | 28 | 43 | 74 | 45 | 58 |
| Karaganda | 26 | 29 | 45 | 48 | 53 | 45 | 63 |
| Semey | 59 | 35 | 27 | 46 | 56 | 45 | 54 |
| Ust-Kamenogorsk | 68 | 78 | 87 | 64 | 45 | 45 | 45 |
| Taldykorgan | N/A | 53 | 45 | 54 | 52 | 45 | 29 |
| Kokshetau | N/A | 0 | 0 | 8 | 68 | 18 | 135 |
| Petropavlovsk | N/A | 37 | 35 | 36 | 38 | 45 | 0 |
| Uralsk | 32 | N/A | N/A | 27 | 63 | 40 | 20 |
| Kyzylorda | N/A | 8 | 40 | 9 | 18 | 0 | 27 |
| Aktobe | N/A | N/A | 25 | 14 | 14 | 9 | 14 |
| Kostanay* | N/A | 9 | 0 | 49 | 85 | 50 | 10 |

* For Kostanay, measured PM concentration was used instead of calculated

consumer per capita in the world in 2014 (Torkmahalleh *et al*. 2020). The climate of Kazakhstan is dry and major lands of the country are steppes and deserts. The average annual precipitation is higher than 300 mm in northern areas, while central and southern parts is estimated to have only 150-200 mm of average annual precipitation. The temperature in winter can decrease up to -45℃ (with average of -4 to -9℃), while in summer it can go up to 45℃ (with average of +19 to +26℃) (Akhanova *et al*. 2020). Also, research study in Nur-Sultan, the capital of Kazakhstan, states that $PM_1$ is found to be the dominant PM fraction (77-94%) (Torkmahalleh *et al*. 2020). The major source of PM in Kazakhstan is not identified yet, and source apportionment with chemical analysis of PM is required (Kerimray *et al*. 2020). However, cheap fossil fuel, especially coal, consumption for heating purposes might explain high PM concentrations during winter seasons (Vinnikov *et al*. 2020). Serious air pollution cases and its impact on people in Kazakhstan were reported by several studies (Kenessary *et al*. 2019, Kerimray *et al*. 2020). Kenessariyev *et al*. (2013) estimated the costs associated with air pollution in Kazakhstan, which was based on the methodology of the World Health Organization, which suggested using the log-linear approximation of the health risk function (Ostro 2004). It was reported that mortality rates due to air pollution in Kazakhstan are very high, several times higher than the number that was estimated

Table 2 The population of cities in Kazakhstan (Committee on Statistics 2018)

| City | Population | Population aged 0-15 | Population aged 16-61 | Population aged 63+ | Total mortality rate per 100,000 people |
|---|---|---|---|---|---|
| Nur-Sultan | 1030577 | 302021 | 652339 | 76217 | 626.3 |
| Zhezkazgan | 91045 | 25702 | 53510 | 11833 | 861.8 |
| Temirtau | 186003 | 41048 | 113829 | 31126 | 861.8 |
| Shymkent | 952170 | 330914 | 547416 | 73840 | 811.5 |
| Balkhash | 78722 | 20047 | 47912 | 10763 | 861.8 |
| Almaty | 1801993 | 413477 | 1170931 | 217585 | 575.3 |
| Aktau | 186238 | 59962 | 107589 | 18687 | 820.4 |
| Atyrau | 327852 | 113809 | 187545 | 26498 | 896.3 |
| Taraz | 355825 | 119277 | 197282 | 39266 | 850.9 |
| Pavlodar | 360048 | 80248 | 221302 | 58498 | 790.9 |
| Ekibastuz | 152853 | 35768 | 97824 | 19261 | 790.9 |
| Karaganda | 501419 | 118898 | 306266 | 76255 | 861.8 |
| Semey | 347284 | 81852 | 216866 | 48566 | 799.1 |
| Ust-Kamenogorsk | 341064 | 70238 | 210445 | 60381 | 799.1 |
| Taldykorgan | 171726 | 48603 | 102028 | 21095 | 887.5 |
| Kokshetau | 159807 | 41935 | 96744 | 21128 | 951.1 |
| Petropavlovsk | 218031 | 44454 | 133405 | 40172 | 813.7 |
| Uralsk | 303971 | 80041 | 183488 | 40442 | 834.9 |
| Kyzylorda | 294415 | 105732 | 164510 | 24173 | 913.3 |
| Aktobe | 477052 | 135429 | 293252 | 48371 | 753.4 |
| Kostanay | 239652 | 51086 | 151873 | 36693 | 782.7 |

by the WHO and reported in “Country profile for the ecological burden of disease” (WHO 2009). While WHO states in their report for Kazakhstan entitled “Country Profile for the Environmental Burden of Disease” that the mean urban $PM_{10}$ concentration in Kazakhstan is 25 μg/m$^3$, Kenessariyev *et al*. (2013) found that the actual concentrations are much higher and are dependent on the pollution characteristics of the city. In 2014, Brody and Golub (2014) reported that the average concentrations of $PM_{2.5}$ in the cities of Almaty and Nur-Sultan are 5 times higher than the standard set by WHO. They also recommended to implement risk assessment procedures, assess costs and benefits, and cost-effectiveness, and that these analytical procedures should be part of the decision-making process to achieve standards (Brody and Golub 2014). Moreover, a high carcinogenic and non-carcinogenic risks due to air pollution with suspended particles, oxides and dioxides of nitrogen and sulfur were observed in most of Kazakhstan’s cities (Kenessary *et al*. 2019). Stricter air guideline values could be implemented to reduce the adverse impact of air pollution on the population, which in turn is associated with economic loss. Implementing air quality standards of developed countries such as OECD air guidelines could help to mitigate the effect of air pollution on people and consequently reduce healthcare-related governmental expenses.

Quantitative assessment of the outcomes of different environmental policies and evaluation of

Table 3 Multiple linear regression coefficients

| City | R-square | Y-intersection ($PM_{2.5}$) | Variable $X_1$ (GRP) | Variable $X_2$ (Population) |
|---|---|---|---|---|
| Nur-Sultan | 0.987 | 0.738 | 0.301 | -0.029 |
| Zhezkazgan | 0.978 | 0.694 | 0.308 | 0.000 |
| Temirtau | 0.981 | -0.450 | 0.454 | 0.998 |
| Shymkent | 0.989 | 0.979 | 0.019 | 0.002 |
| Balkhash | 0.978 | 0.129 | 0.843 | 0.034 |
| Almaty | 0.979 | 0.622 | 0.085 | 0.295 |
| Aktau | 0.986 | 2.522 | 0.089 | -1.611 |
| Atyrau | 0.945 | 1.202 | 0.108 | -0.316 |
| Taraz | 0.983 | 1.841 | -0.376 | -0.460 |
| Pavlodar | 0.994 | 3.933 | -0.475 | -2.459 |
| Ekibastuz | 0.756 | -0.926 | 2.391 | -0.470 |
| Karaganda | 0.944 | -3.380 | 0.390 | 4.040 |
| Semipalatinsk | 0.987 | -2.716 | -0.014 | 3.727 |
| Ust-Kamenogorsk | 0.994 | 1.495 | -0.168 | -0.327 |
| Taldykorgan | 0.999 | 1.396 | -0.020 | -0.377 |
| Kokshetau | 0.959 | -3.304 | 0.641 | 3.685 |
| Petropavlovsk | 0.872 | -2.673 | 0.043 | 3.694 |
| Uralsk | 0.960 | 1.117 | -0.113 | -0.003 |
| Kyzylorda | 1.000 | 1.704 | -0.059 | -0.645 |
| Aktobe | 0.990 | 1.186 | -0.029 | -0.157 |
| Kostanai | 0.992 | -1.907 | 0.109 | 2.816 |

costs and advantages should be implemented for the decision making regarding environmental policies in Kazakhstan. In this regard, two scenarios were assumed: “business as usual” (no change in standards) and “OECD standards” (implementing OECD standards). Thus, the study seeks to determine economic benefits from a change in the environmental policy of Kazakhstan in the long run. In particular, objectives are (1) to investigate expected values of the gross regional product (GRP) and PM concentrations in the atmosphere of Kazakhstan cities until 2050, and (2) to elucidate and compare the impact of emitted air pollutant on premature deaths, diseases, health care costs and work capacity in both scenarios.

## 2. Materials and methods

### *2.1 Study area and data source*

The study area covers all major cities of Kazakhstan including Nur-Sultan, Zhezkazgan, Temirtau, Shymkent, Balkhash, Almaty, Aktau, Atyrau, Taraz, Pavlodar, Ekibastuz, Karaganda, Semipalatinsk, Ust-Kamenogorsk, Taldykorgan, Kokshetau, Petropavlovsk, Uralsk, Kyzylorda, Aktobe, Kostanay (Fig. S1). Data on concentrations of PM from 2011 to 2017 were taken from information bulletins on the state of the environment of Regional State Enterprise (RSE) “Kazhydromet” (Table 1) (Kazhydromet 2018). RSE “Kazhydromet” continuously measured the concentration of total suspended particles (TSP) and $PM_{10}$ at national air monitoring network’s observation posts comprising manually controllable and automatic stations. Measurement was conducted based on gravimetric and light scattering approaches. All locations of observation posts are listed in the Table S1. Due to the unavailability of measurements, $PM_{10}$ concentrations were determined based on the ratio of $TSP/PM_{10} = 0.45$, following the work by the World Bank (World Bank 2012). Table 2 demonstrates demographic data (population and mortality rates) used for estimating future concentrations (Committee on Statistics 2018).

### *2.2 Statistical analysis*

Future concentrations of air pollutants were estimated using multiple regression analysis in Excel 2016 software. Hence, correlation coefficients of the regression equation were obtained for the dependence of the growth index of $PM_{10}$ concentration on growth indices of GRP and population. The growth index is defined as the values of some parameter (concentration, population or GRP) in the current year divided by the values of the same parameter in a reference year (2011). Data on growth indices of the GRP and population were obtained from the Committee on Statistics of the Ministry of National Economy. Since lack of data on GRP of cities separately, the GRP growth index of the regions, was the particular city is located, were assumed to be equal to the GRP growth index in the city (Committee on Statistics 2018) (Figs. S2 and S3). Calculation of the growth index of $PM_{10}$ was reported by (Kerimray *et al*. 2018). General statistical equations by the method of least squares were used to calculate the coefficients based on these 2011-2017 data. The multiple linear regression coefficients for $PM_{2.5}$ (y), GRP ($X_1$) and population ($X_2$) are presented in Table 3.

### *2.3 Assessment of mortality and morbidity*

Assessment of mortality was conducted using the estimated concentrations of $PM_{10}$ using “concentration-response” functions developed by the World Health Organization were used in this study (Ostro 2004). The method used in this study estimates the impact of PM on population (long-term exposure of adults to $PM_{2.5}$ associated with cardiopulmonary mortality & lung cancer and short-term exposure of children to $PM_{10}$ associated with the respiratory mortality) via linear “concentration-response” function. It is worth pointing out that the original methodology guideline was designed for estimation of mortality for adults > 30 years old and children < 5 years old. However, due to the availability of demographic data, the exposed population was assumed to include adults (> 18 years old). For children, only demographic data for the age group of 0-15 years old was available. Therefore, it was assumed that the population of children aged 0-5 years old is the third (33%) of the population of all children (0-15 years old), who are living in urban areas. The average percent of children aged 0-15 living in cities is 26.8% of the total urban population based on a comparison of all cities. Thus, according to our assumption, children living in urban areas and aged < 5 years old comprise about 8.8% of the urban population (0.33 × 0.268). This correlates well with existing studies because the percentage of children aged < 5 years old in urban areas was reported to be ~ 8.2% in developing countries (UNDESA 2017).

The linear relationship between the concentration of air pollutants and associated health effects are demonstrated in Eq. (1). RR is the relative risk. X0 is a target concentration of pollutants and is

Table 4 Methodology for calculating the relative risk of mortality (Ostro 2004)

| Parameter | $\beta$ (lower-upper bound) | DALY/10000 cases |
|---|---|---|
| Mortality from cardiopulmonary diseases for adults (long-term) | 0.00893<br>(0.00322-0.01464) | 80000 |
| Mortality from lung cancer for adults (long-term) | 0.01267<br>(0.00432-0.02102) | 80000 |
| Mortality of acute respiratory diseases of the lower respiratory tract (ARI NDP) of children under 5 years (short-term) | 0.00166<br>(0.00034-0.0030) | 340000 |

assumed to be 15 μg/m$^3$ for $PM_{10}$ (the lowest $PM_{10}$ level observed in rural areas of Kazakhstan) and 7.5 μg/m$^3$ for $PM_{2.5}$ (World Bank 2012). The target concentration is used to estimate the overall damage of human health by atmospheric pollution and represents the lowest level that could be achieved by proper policy measures. X is the existing concentration of an air pollutant. $\beta$ is a concentration-response coefficient, i.e., environmental burden of disease representing the increase in the relevant health effect due to the increase in air pollutant's concentration by 1 μg/m$^3$. Table 4 demonstrates the details of the calculation of relative risks of mortality from air pollution-related diseases.

Due to the unavailability of statistical data on $PM_{2.5}$, the $PM_{2.5}/PM_{10}$ ratio was assumed to convert $PM_{10}$ data to $PM_{2.5}$ data. Ostro (2004) used a ratio of 0.5 for developing countries (Ostro 2004). Different studies demonstrate a wide range of ratios from 0.31 in Bahrain to 0.7 in northern China (Coskuner *et al*. 2018, Duan *et al*. 2015, Zhao *et al*. 2019). The ratio was heavily affected by local meteorological conditions. Stable atmospheric conditions are associated with a higher ratio (Xu *et al*. 2017). Kenessariyev *et al*. (2013) assumed ratios of 0.2-0.3 for steppe areas, which are likely to have sandstorms, and 0.4 for areas with a low probability of sandstorms in Kazakhstan (Kenessariyev *et al*. 2013). In this study, a rough assumption of $PM_{2.5}/PM_{10}$ ratio = 0.45 was accepted because the objective of the study was not to estimate the mortality and morbidity but to estimate the difference in health-related costs between the 2 scenarios.

$$RR = \exp[\beta(\mathrm{X} - \mathrm{X0})] \qquad (1)$$

The mortality was calculated using Eq. (2). $E$ is the number of deaths, and $AF$ is related to an attributable fraction and was calculated with Eq. (3). $B$ is the overall mortality rate related to a relevant health effect and $P$ is the exposed population (Ostro 2004). Data for mortality from a specific health effect (cardiopulmonary mortality, lung cancer and acute lower respiratory infection-related total mortality) was not available. Therefore, we used the method of World Bank study to estimate specific mortality. The percentage of cardiovascular and lung cancer mortality in adults was assumed to be 35.5% and 2% of total mortality, respectively. For children under 5 years old, mortality from acute lower respiratory infections was assumed to be 6.8% of total mortality.

$$E = AF \times B \times P \qquad (2)$$

$$AF = (RR - 1)/RR \qquad (3)$$

The morbidity was estimated by calculating the number of chronic bronchitis cases, the number of hospitalizations, appeals for urgent medical help, days of limited activity, diseases of the lower respiratory ways in children and symptoms of respiratory diseases. For the assessment of the relationship of morbidity incidence to $PM_{10,}$ its response coefficients by the World Bank were used

Table 5 Coefficients of reaction to the impact of urban atmospheric pollution, to calculate the incidence rate (World Bank 2012)

| Impact on health $PM_{10}$ | Unit | Impact on 1 $\mu g/m^3$ |
|---|---|---|
| Chronic bronchitis | 100000 adults | 0.9 |
| Number of hospitalizations | 100000 population | 1.2 |
| Appeals for urgent medical help | 100000 population | 23.5 |
| Days of limited activity | 100000 adults | 5750 |
| Diseases of the lower respiratory ways in children | 100000 children | 169 |
| Symptoms of respiratory diseases | 100000 adults | 18300 |

Table 6 The cost of a unit of medical care and temporary losses associated with disease (World Bank 2012)

| Costs due to illness | Unit | Cost of one unit (USD) |
|---|---|---|
| Chronic bronchitis ($PM_{10}$) | Day | 14620 |
| Hospitalization ($PM_{10}$) | Visit | 587 |
| Requests for emergency medical care ($PM_{10}$) | Visit | 79 |
| Days of limited activity ($PM_{10}$) | Day | 3.4 |
| Diseases of the lower respiratory tract in children ($PM_{10}$) | Day | 63 |
| Symptoms of respiratory diseases ($PM_{10}$) | Day | 0.8 |

based on the analysis of international studies (Table 5).

### 2.4 Calculations of health care costs

DALY is a disability-adjusted life year, i.e., the sum of years lost due to premature death or disability (World Bank 2012). Table 4 also represents the values of DALY per 10000 cases of health effects that were obtained from the World Bank study. The monetary effect of mortality can be estimated using Eq. (4).

$$\text{Monetary effect} = \text{Gross Domestic Product} \times \text{DALY} \quad (4)$$

Morbidity-related costs, i.e., health care costs were calculated using the World Bank approach which includes the adapted approach to human capital, the value of statistical life, and the cost of illness. Table 6 shows the costs associated with the treatment of diseases and the loss of time due to the disease, which is based on data on medical costs received from the Ministry of Health of the Republic of Kazakhstan and information on wages in Kazakhstan and calculated by the World Bank experts (World Bank 2012).

## 3. Results and discussion

### 3.1 Estimation of concentrations of $PM_{2.5}$ and $PM_{10}$ until 2050

In the “Business as usual” scenario, the concentrations until 2050 followed the same trend as those from 2011 to 2017 (mostly growing), while the “OECD” scenario’s estimated for future

Table 7 Comparison of Kazakhstani standard values with the World Health Organization and the European Union standards (European Commission 2019, Kazhydromet 2018, WHO 2018)

| Pollutant | Concentration, µg/m$^3$ | | | Time interval |
|---|---|---|---|---|
| | WHO | EU | Kazakhstan | |
| $PM_{10}$ | 20 | 40 | 300 (max. single concentration) | 1 year |
| | 50 | 50 | 60 | Average daily |
| $PM_{2.5}$ | 10 | 25 | 160 (max. single concentration) | 1 year |
| | 25 | | 35 | Average daily |

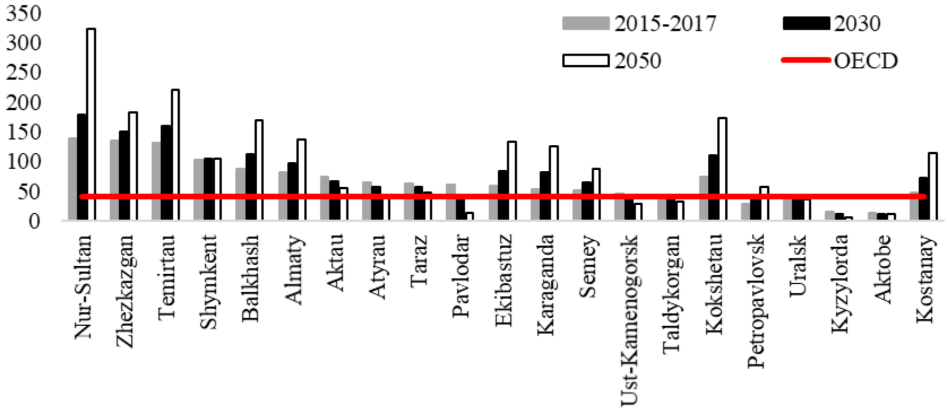

Fig. 1 Predicted concentrations of $PM_{10}$ in the air up to 2050 according to the “Business as usual” scenario, µg/m$^3$

$PM_{10}$ and $PM_{2.5}$ concentrations were calculated based on the guideline values for the air pollutants of EU. “OECD” scenario assumed that, by the year 2030, the air pollutant level will reach the annual limit value set in the EU standard (40 µg/m$^3$, Table 7). Table S2 demonstrates the predicted concentrations for the “OECD” scenario. The projection was done for years 2017 (initial year), 2020, 2025, 2030, 2035, 2040 and 2050. Concentrations in the “OECD” scenario was calculated based on assumption that the initial concentration of PM decreases by the same amount each period until 2030 (there are 3 periods, i.e., 2017-2020, 2020-2025, 2025-2030). The average concentration in 2015-2017 in Nur-Sultan (138 µg/m$^3$) for an example was assumed to decrease by 32.1 µg/m$^3$ each year until 2030 because (138 − 40)/3 = 32.1 µg/m$^3$. It is worth pointing out that if concentrations decreased in the “Business as usual” scenario (Pavlodar, Ust-Kamenogorsk, Taldykorgan, Uralsk, Kyzylorda and Aktobe), the same trend was assumed in “OECD scenario”, i.e., predicted concentrations were left as they are in “OECD” scenario if they were < 40 µg/m$^3$ to prevent overestimation of results.

To calculate $PM_{10}$ concentrations until 2050 with no amendment in air guidelines, estimations of future populations and GRP values were needed. The estimated future population of each city and GRP until 2050 can be seen in Figs. S4 and S5, respectively. The future population and GRP were assumed to grow at an exponential rate. Population-projected growth rates were high in Shymkent, Nur-Sultan, Almaty, Atyrau and Uralsk because of the migration of citizens (Olzhaev 2014, Userbayeva 2019, Zhusupova and Kenesov 2012). Fig. S5 shows that Almaty and Nur-Sultan have the largest increase in GRP because the business activity and finance are centered in

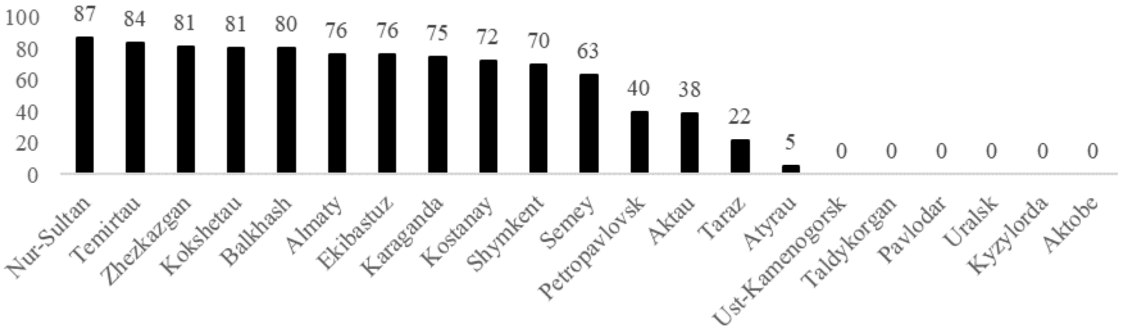

Fig. 2 Mortality reduction in 2050 in the scenario “OECD Standards” in comparison to the “Business as usual” scenario in %

Almaty, while Nur-Sultan is the capital of the country with a fast-growing population and migration rate into the city.

The estimated future concentrations of $PM_{10}$ and $PM_{2.5}$ for the “Business as usual” scenario were demonstrated in Fig. 1. The estimated future $PM_{2.5}$ concentrations were demonstrated in Table S3. The air pollutants’ concentrations were exceeded OECD’s annual limit value for $PM_{10}$ by 2050 in all cities, except Kyzylorda (5.9 $\mu g/m^3$), Aktobe (10.6 $\mu g/m^3$), Pavlodar (13.5 $\mu g/m^3$), Taldykorgan (32.1 $\mu g/m^3$), Uralsk (36.5 $\mu g/m^3$) and Ust-Kamenogorsk (28.8 $\mu g/m^3$). At the same time, Aktau, Atyrau, Taraz, Pavlodar, Ust-Kamenogorsk, Taldykorgan, Uralsk, Kyzylorda and Aktobe demonstrated a declining trend in the concentration level of $PM_{2.5}$ and $PM_{10}$ (Tables S2, and S3 and Fig. 1). Economic growth and population growth were assumed to be the two main reasons for the increase in the pollutant concentration of the cities. Their decrease or increase would directly influence the concentrations in the future.

Some limitations were inherent to methodology. Firstly, the average annual concentrations of $PM_{10}$ demonstrated fluctuation during 2011-2017. The quality of the monitoring system and a small number of samples could potentially be a reason. Many assumptions, particularly for the $PM_{2.5}/PM_{10}$ ratio, could also contribute to uncertainty. Moreover, other factors may contribute to $PM_{10}$ and $PM_{2.5}$ pollution other than economic situation and demographics. According to European Environmental Agency, there are a wide range of air pollutants emitters including both man-made and natural sources, e.g., fossil fuel consumption in transport, household, electricity generation and industry. Emission from chemical and mining industries using various types of solvents in their industrial processes could be the sources. Agriculture and waste treatment by burning are also contributing to air pollution (López-Aparicio *et al*. 2013, Lucarelli *et al*. 2019). Some natural air pollution emitters are volcanoes, dust from winds, fine particles of sea-salt and plants that emit volatile organic compounds (EEA 2019). Also, urban traffic could be one of the most-influencing sources of air pollution. Coal consumption and population density rather than total population could contribute to air pollution as well (Sun *et al*. 2019, Vardoulakis and Kassomenos 2008). Meteorological conditions (precipitation, wind speed, temperature) were considered to be significant factors as well (Saramak 2019). Finally, more advanced statistical models have been currently used. Multivariate analysis of data is one of the most convenient and efficient techniques for the big data analysis. For the analysis in environmental science and management, a spatial interpolation method has been commonly used for the purpose, e.g., a geostatistical method such as ordinary kriging (Núñez-Alonso *et al*. 2019). The study has been significantly focusing on the

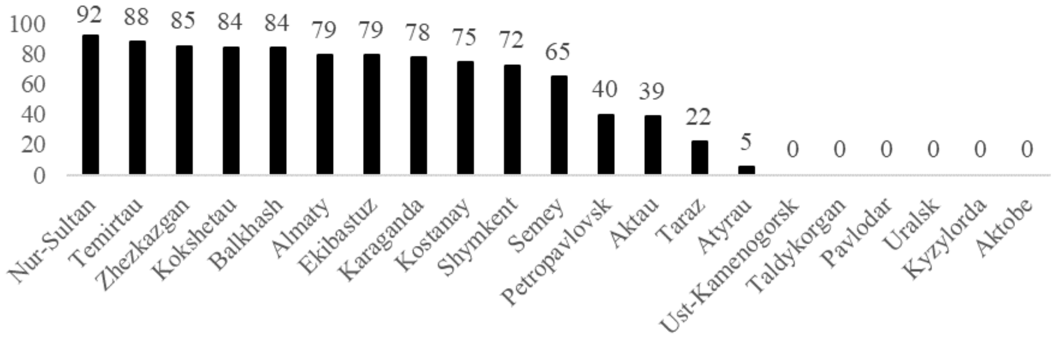

Fig. 3 Reduction in the incidence of chronic bronchitis in 2050 by the “OECD Standards” scenario in comparison to the Business as usual scenario in %

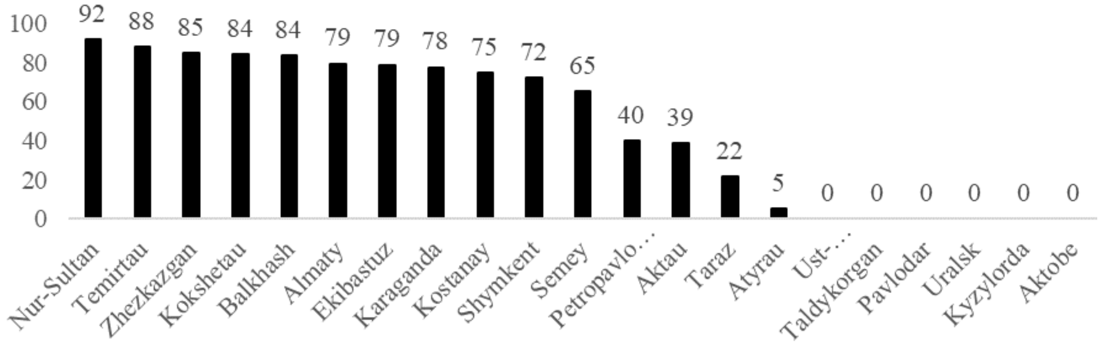

Fig. 4 Reduced days of limited activity in 2050 in the “OECD Standards” scenario in comparison to the “Business as usual” scenario in %

estimation of the monetary effect of air pollution in the country.

### *3.2 Impact of transition into OECD standards on mortality and diseases caused by emitted air pollutants*

Fig. 2 shows the implementation of the “OECD scenario” emission restrictions leading to a reduction of mortality in a half of the cities of Kazakhstan by 2050. Reduction of the mortality in the cities of Kazakhstan reached up to 87% including Nur-Sultan (87%), Temirtau (84%), Zhezkazgan (81%), Kokshetau (81%) and Balkhash (80%). Some cities showed a minimum or zero reduction in mortality since their air quality was under or close to OECD standards (i.e., Pavlodar, Atyrau, Ust-Kamenogorsk, Uralsk, Taldykorgan, Kyzylorda and Aktobe). In general, the transition to “OECD standards” leads to 71.7% less air pollution-related mortality in 2050, i.e., 3216 less premature deaths in 2030 and 6802 in 2050 in all cities. Moreover, it leads to a 56% decrease in morbidity cases on average in 2050 (8084, 14893, 291647, 51646357, 579426, 164370146 fewer mortality cases for chronic bronchitis, number of hospitalizations, requests for urgent medical help, days of limited activity, lower respiratory ways’ disease cases in children and symptoms of respiratory disease, respectively).

Morbidity was calculated using 6 factors, but chronic bronchitis and days of limited activity were considered as the most important factors because their contribution to overall morbidity costs

Table 8 Estimated costs of morbidity and mortality associated with air pollution, $ million

| City | Baseline | Business as usual | | OECD | |
|---|---|---|---|---|---|
| | 2017 | 2030 | 2050 | 2030 | 2050 |
| Nur-Sultan | 146.5 | 304.7 | 1120.3 | 54.7 | 134.9 |
| Zhezkazgan | 10.7 | 14.6 | 24.4 | 3.0 | 4.3 |
| Temirtau | 22.6 | 33.8 | 62.6 | 6.5 | 9.3 |
| Shymkent | 47.0 | 77.2 | 175.1 | 22.2 | 49.1 |
| Balkhash | 6.0 | 9.8 | 20.4 | 2.7 | 3.8 |
| Almaty | 167.3 | 332.9 | 1038.6 | 106.3 | 238.4 |
| Aktau | 14.8 | 14.9 | 14.2 | 7.2 | 8.7 |
| Atyrau | 37.0 | 37.6 | 30.8 | 22.6 | 29.2 |
| Taraz | 10.2 | 10.1 | 9.1 | 6.1 | 7.1 |
| Pavlodar | 17.9 | 13.0 | 0.0 | 11.2 | 0.0 |
| Ekibastuz | 7.1 | 12.7 | 26.4 | 4.8 | 6.1 |
| Karaganda | 21.5 | 44.4 | 101.4 | 17.3 | 24.8 |
| Semey | 11.3 | 19.5 | 41.9 | 9.9 | 15.1 |
| Ust-Kamenogorsk | 9.3 | 10.1 | 8.4 | 10.1 | 8.4 |
| Taldykorgan | 3.1 | 3.7 | 4.3 | 3.7 | 4.3 |
| Kokshetau | 8.4 | 15.1 | 28.8 | 4.1 | 5.1 |
| Petropavlovsk | 2.3 | 5.2 | 11.1 | 5.2 | 6.7 |
| Uralsk | 9.2 | 11.9 | 17.2 | 11.9 | 17.2 |
| Kyzylorda | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Aktobe | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Kostanay | 6.8 | 13.2 | 27.4 | 5.9 | 7.3 |
| Total | 559.1 | 984.3 | 2762.5 | 315.3 | 579.8 |

were among the highest. Under the “OECD scenario”, the incidence of chronic bronchitis decreased to 92% in Nur-Sultan (92%), Temirtau (88%), Zhezkazgan (85%), Kokshetau (84%), and Balkhash (84%) by 2050 (Fig. 3). Overall, 3420 fewer cases of incidence chronic bronchitis in 2030, and 8084 fewer cases in 2050 occurred under the “OECD scenario”. Fig. 4 shows the changes in days of limited activity after changing emission restrictions into the “OECD Standards” scenario. Days of limited activity also decreased under the “OECD scenario” to 92% in Nur-Sultan with the same percentage difference in each city as in the case of chronic bronchitis. Similar to a reduction in mortality, four cites (i.e., Pavlodar, Ust-Kamenogorsk, Taldykorgan and Uralsk) did not experience any changes in the incidence of chronic bronchitis and the number of days of limited activity since the emission of those cities were similar or below “OECD Standards”.

To conclude, the transition into “OECD Standards” leads to positive consequences such as a substantial reduction in mortality of most of the cities, reduction in incidences of chronic bronchitis, and decreased the days of limited activity in the majority of cities. Only four cities remained at the same level regardless of the change in emission restriction standards, comprising only 14% of the total urban population of Kazakhstan. On the other hand, 86% of all cities’ population was experiencing improvement in terms of the health effect of air pollution in case of

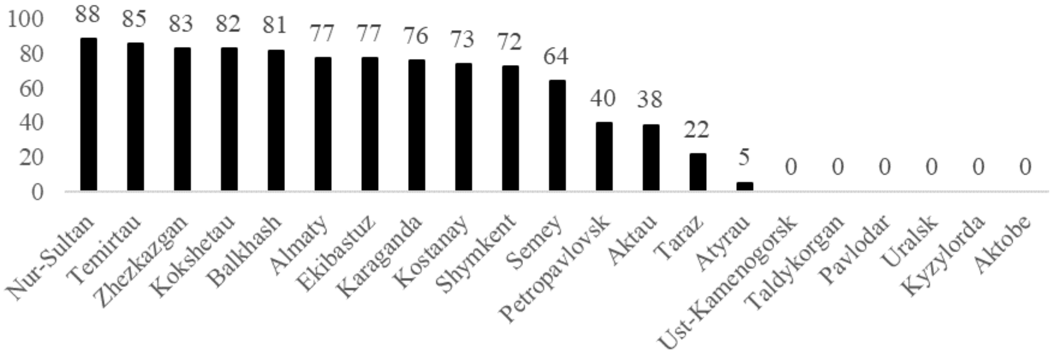

Fig. 6 Cost reduction from morbidity and mortality in 2050 in the “OECD Standards” scenario in comparison to the “Business as usual” scenario in %

transition to the “OECD” scenario. Such a significant impact on public health plays a crucial role in the economy of the country since the health care of the patients requires financial support, which is discussed in the next section.

### *3.3 Impact of transition into OECD standards on health care costs caused by emitted air pollutants*

Table 8 illustrates the estimated costs (USD) related to incidence and premature deaths caused by exposure to air pollution in all cities of Kazakhstan in 2017, 2030 and 2050. Total cost in all cities increased from $559 million in 2017 by 1.8 times in 2030 ($984.3 million) and increased by 4.9 times in 2050 ($2762.5 million) in case if the current situation persists. As can be seen from Table 8, the highest cost of morbidity and mortality is in the cities of Almaty, Nur-Sultan, Karaganda and Shymkent. This is because Almaty, Nur-Sultan and Shymkent are the cities of republican significance with a fast-growing population by > a million, while the other two cities have developed industries, i.e., Karaganda is one of the main coal producers in the country. In the case of the “OECD” scenario, the total cost in all cities increased only by 4% in 2050 ($579.8 million) compared to 2017, while in 2030, it decreased by 43% ($315.3 million). The cost of health care due to air pollution could significantly influence the country’s economy under assumption that the future economic growth remains at the same level and there is no change in air pollution standards. Hence, it is critical to implement the preliminary measures against current emission restriction standards to protect a significant part of the population from the possibility of mortality and morbidity by the air pollution.

In case, if emission restriction policies of 21 Kazakhstan cities could be changed to the OECD air quality standards, the economic cost of morbidity and mortality associated with air quality would decrease by $669 million in 2030 and $2183 million in 2050. The greatest savings in 2050 could be found to be in the cities of Nur-Sultan and Almaty, $985 million, and $800 million, respectively, since these cities had the largest susceptible population and high level of air pollution. On the other hand, a cost reduction relative to the 2050’s cost (as a percentage) is also important in addition to their absolute difference (Fig. 6). The highest cost reduction relative to the 2050’s cost in the “Business as usual” scenario occurs in Nur-Sultan and Temirtau, 88% and 85% respectively. Nur-Sultan is the capital of the country with one of the largest populations and air

Table 9 Comparison of the study with published works

| Location | Contaminant | Air pollution reduction scenario | Reduction in mortality | Reduction in healthcare costs (USD) | Reference |
|---|---|---|---|---|---|
| Kazakhstan, 22 major cities | PM10 and PM2.5 | Implementing stricter air quality standards by 2050 (OECD) | 6802 in 2050 (72%) | $2.2 billion (2050) | This study |
| South Africa | PM2.5 | Implementing stricter air quality standards (WHO) | 28000 | $29.1 billion (4.5% of South Africa's 2012 GDP) | (Altieri and Keen 2019) |
| Shiraz, Iran | $NO_2$, $SO_2$, PM2.5, PM10, $O_3$ | Addition mortalities due to difference between real concentrations and background level of 10 $\mu g/m^3$ | 911 cases (2016), 346 cases (2017) | Not calculated | (Bonyadi *et al.* 2020) |
| Beijing, China | $SO_2$ | Addition mortalities due to difference between real concentrations and background level of 20 $\mu g/m^3$ | 884 and 27854 outpatient cases | 477 million RMB Yuan (2016)<br>(~ $3.2 billion) | (Wu *et al.* 2020) |
| EU | PM2.5 | Achieving 50% reduction in agricultural PM2.5 emissions | ~140000/year | $407 billion /year | (Giannadaki *et al.* 2018) |
| Changsha, China | PM2.5 | Reduction in emissions due to change in urban industrial land allocation | 60.8% | $0.69 billion | (Xu *et al.* 2020) |
| New York City, USA | PM2.5 | Reduction in emissions due-to COVID-19 lockdowns | 3455-7791 | $30.9-$69.7 billion | (Perera *et al.* 2021) |

pollution, while Temirtau is an industrial city with developed metallurgy, which causes severe air pollution problems (Abdurasulov 2018, Long 2020).

Table 9 demonstrates the comparison of the study with published works. Overall, reducing the exposure to PM10 and PM2.5 by any means leads to both public health and monetary benefits worldwide. Compared to state-scale studies (South Africa and EU) and even single city-focused study (New York City), Kazakhstan's reduction in mortality is relatively small probably due to Kazakhstan's small population (~18 million people (World Bank 2021)) or differences in the methodology. Monetary effect was approximately lower in developing countries (< $30 billion) (Kazakhstan, China, South Africa) compared to cost reduction in developed states (USA and EU).

Additional expenditures on health care of patients due to air pollution and days of limited activity of the population would cause a significant economic impact. Considering the GDP of Kazakhstan, the cost of morbidity and mortality was 0.34% of GDP ($166800 million (World Bank 2017)) in 2017. At the most optimistic scenario of Kazakhstan's GDP's growth (by 4.5 in 2050 (Syzdykbaev 2016)), the cost of air pollution-related health problems could constitute 0.37% of estimated GDP and increase more if the future GDP could be lower than this estimate. Thus, the cost of air pollution would increase with years, being a minimum of 0.37% of GDP and a maximum of 1.66% (assuming that the GDP would be the same in 2050 in the worst scenario). In contrast, in case of changes in air quality standards to EU air quality standards ("OECD scenario"), the economic costs of morbidity and mortality would comprise 0.35% in 2050 in the case of the worst GDP growth scenario (same 2017's GDP in 2050) and decrease to 0.08% in the optimistic case. Thus, a change of air quality standards can lead to huge savings, which could positively influence the country's economy and decreased the level of morbidity and mortality of its citizens.

Numerous factors might affect the validity of results. Although the current investigation just focused on $PM_{10}$ and $PM_{2.5}$, there are other pollutants, which may affect mortality such as CO, $NO_x$, $SO_2$, ozone, and heavy metals (Pervin *et al*. 2008). Thus, the derived number of mortalities and costs could be further increased by adding more pollutants in the assessment. The consideration of different scenarios could further increase costs. For example, short-term acute effects in adults could be significant for the cost estimations. Moreover, other significant and costly health effects of air pollution could be overlooked. Studies are suggesting a connection of dementia and low birth weight to air pollution, for instance (Pimpin *et al*. 2018). Intangible effects such as pain and suffering have been also monetized in the literature (Pervin *et al*. 2008). The PMs in this study was derived from outdoor measurements, while people spent most of the time indoors. Indoor pollution levels are considered to be more serious and influential than that of outdoor pollution (Kumar *et al*. 2016). It is worth pointing out that indoor activities such as cooking and heating significantly deteriorate the quality of air (Pervin *et al*. 2008). In rural areas of Kazakhstan, where air pollution-producing heating with stoves is abundant, assessment should be done as well to cover all populations in the country. Thus, costs could be underestimated in the study because only outdoor effects were taken into account. Moreover, mostly long-term effects were considered, while there are also short-term costs of air pollution for adults, which may add up to the derived results. On the other hand, there are factors, which may overestimate the conclusions of the study such as using the value of a statistical life approach to estimate costs. It is designed for accidental deaths and working-age people, while air pollution affects the elderly and children at most, thereby it could lead to overestimation. Therefore, using the value of life year approach could enhance the quality of results (Delucchi *et al*. 2002, Pervin *et al*. 2008). The threshold (the $PM_{10}$ and $PM_{2.5}$ concentrations level at which no health effect is observed) has no scientific derivation and different studies use different thresholds varying from 10 to 25 $\mu g/m^3$ (Gao *et al*. 2015). Using a lower threshold may overestimate results because it results in a higher and overestimated difference between the current concentration and threshold.

Uncertainty is inherent to not only factors and variables but also to methodology itself. The methodology could be improved by employing stochastic methods over deterministic to show the overall picture of the distribution of costs and shed a light on the effect of parameters on the overall cost. Increasing the number of observations would also enhance the quality of results. Finally, the mortality's concentration-response factors based on epidemiological studies could contribute to uncertainty a lot. They are based on foreign populations and may not be applicable in Kazakhstan. Research on the derivation of local dose-response coefficients could help further elucidate the costs of air pollution. Moreover, it is important to note that the dose-response model was derived from a heterogeneous population. It is recommended to categorize the estimations by age, gender and income to identify vulnerable groups within the population. Further improvements for quantifying the air pollution effect may include the risk assessment procedures for urban populations. Brody and Golub (2014) suggested to establish a risk assessment institute and to install proper modern monitoring and information systems, which can produce high-quality air pollution data to obtain a better quality estimations. Overall, the study demonstrated the negative effect of the current air quality regulations in Kazakhstan and highlights the need to alter environmental policy and switch to European guidelines. This study is significant for policymaking and the enhancement of environmental regulations in Kazakhstan.

## 4. Conclusions

Most of the Kazakhstan cities do not meet the WHO standards of $PM_{10}$ concentration. The only 6 cities (Kyzylorda, Aktobe, Pavlodar, Taldykorgan, Uralsk and Ust-Kamenogorsk) would meet the environmental condition of $PM_{10}$ lower than the WHO limit by 2050. The incidences and deaths caused by ambient air pollution would potentially lead to an increase of economic costs by 2050 ($559.1 million in 2017 to $2762.5 billion by 2050). Among all cities, the highest mortality reduction was found in Nur-Sultan, Temirtau and Zhezkazgan. Nur-Sultan is the Kazakhstan capital of Republican significance with the highest rate of development, while Temirtau and Zhezkazgan are the cities with developed coal and copper mining industries. All predicted negative consequences of ambient air pollution make it essential to change the current environmental policy of the country, which could effectively decrease the total losses. Changes in the limit of $PM_{10}$ concentration in the environmental policy of Kazakhstan to that in the OECD standards could directly lead to a decrease in the losses of the country’s economy and citizens’ health. The cost related to morbidity and mortality by the air pollution would possibly decrease by $669 million in 2030 and $2,183 million in 2050 with the greatest saving in Almaty and Nur-Sultan.

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## References

Abdurasulov, A. (2018), “Black now troubles pollution-weary Kazakhs in Temirtau”, *BBC News*, U.K. https://www.bbc.com/news/world-asia-42653738.

Akhanova, G., Nadeem, A., Kim, J.R. and Azhar, S. (2020), “A multi-criteria decision-making framework for building sustainability assessment in Kazakhstan”, *Sustain. Cities Soc.*, **52**, 101842. https://doi.org/10.1016/j.scs.2019.101842.

Altieri, K.E. and Keen, S.L. (2019), “Public health benefits of reducing exposure to ambient fine particulate matter in South Africa”, *Sci. Total Environ.*, **684**, 610-620. https://doi.org/10.1016/j.scitotenv.2019.05.355.

Amoatey, P., Omidvarborna, H., Baawain, M.S. and Al-Mamun, A. (2019), “Emissions and exposure assessments of SOX, NOX, PM10/2.5 and trace metals from oil industries: A review study (2000-2018)”, *Process Saf. Environ. Prot.*, **123**(2), 215-228. https://doi.org/10.1016/j.psep.2019.01.014.

Anderson, H.R., Spix, C., Medina, S., Schouten, J.P., Castellsague, J., Rossi, G., Zmirou, D., Touloumi, G., Wojtyniak, B., Ponka, A., Bacharova, L., Schwartz, J. and Katsouyanni, K. (1997), “Air pollution and daily admission for chronic obstructive pulmonary disease in 6 European cities: Results from the APHEA project”, *Eur. Respir. J.*, **10**, 1064-1071.

Atkinson, R.W., Fuller, G.W., Anderson, H.R., Harrison, R.M. and Armstrong, B. (2010), “Urban ambient particle metrics and health: A time-series analysis”, *Epidemiology*, **21**(4), 501-511. https://doi.org/10.1097/ede.0b013e3181debc88.

Bonyadi, Z., Arfaeinia, H., Ramavandi, B., Omidvar, M. and Asadi, R. (2020), "Quantification of mortality and morbidity attributed to the ambient air criteria pollutants in Shiraz city, Iran", *Chemosphere*, **257**, 127233. https://doi.org/10.1016/j.chemosphere.2020.127233.

Brody, M. and Golub, A. (2014), "Improving air quality and health in Kazakhstan: monitoring, risk assessment and management", *Sci. Pract. J. Med.*, **2**(4), 1-3.

Burnett, R.T., Smith-Doiron, M., Stieb, D., Cakmak, S. and Brook, J.R. (1999), "Effects of particulate and gaseous air pollution on cardiorespiratory hospitalizations", *Arch. Environ. Health*, **54**(2), 130-139. https://doi.org/10.1080/00039899909602248.

Cadelis, G., Tourres, R. and Molinie, J. (2014), "Short-term effects of the particulate pollutants contained in Saharan dust on the visits of children to the emergency department due to asthmatic conditions in Guadeloupe (French Archipelago of the Caribbean)", *PLoS ONE*, **9**(3), 91136. https://doi.org/10.1371/journal.pone.0091136.

Chiang, T.Y., Yuan, T.H., Shie, R.H., Chen, C.F. and Chan, C.C. (2016), "Increased incidence of allergic rhinitis, bronchitis and asthma, in children living near a petrochemical complex with $SO_2$ pollution", *Environ. Int.*, **96**, 1-7. http://doi.org/10.1016/j.envint.2016.08.009.

Chuang, K.J., Yan, Y.H., Chiu, S.Y. and Cheng, T.J. (2011), "Long-term air pollution exposure and risk factors for cardiovascular diseases among the elderly in Taiwan", *Occup. Environ. Med.*, **68**(1), 64-68. http://doi.org/10.1136/oem.2009.052704.

Committee on Statistics (2018), "Population Statistics", Committee on Statistics of the Ministry of National Economy of the Republic of Kazakhstan, Kazakhstan.

Correia, A.W., Pope III, C.A., Dockery, D.W., Wang, Y., Ezzati, M. and Dominici, F. (2015), "The effect of air pollution control on life expectancy in the United States: An analysis of 545 US counties for the period 2000 to 2007", *J. Invest. Dermatol.*, **135**(2), 612-615. https://doi.org/10.1097/EDE.0b013e3182770237.

Coskuner, G., Jassim, M.S. and Munir, S. (2018), "Characterizing temporal variability of PM 2.5 /PM 10 ratio and its relationship with meteorological parameters in Bahrain", *Environ. Forensics*, **19**(4), 315-326. https://doi.org/10.1080/15275922.2018.1519738.

Dappe, V., Uzu, G., Schreck, E., Wu, L., Li, X., Dumat, C., Moreau, M., Hanoune, B., Ro, C.U. and Sobanska, S. (2018), "Single-particle analysis of industrial emissions brings new insights for health risk assessment of PM", *Atmos. Pollut. Res.*, **9**(4), 697-704. https://doi.org/10.1016/j.apr.2018.01.016.

Delucchi, M.A., Murphy, J.J. and McCubbin, D.R. (2002), "The health and visibility cost of air pollution: A comparison of estimation methods", *J. Environ. Manag.*, **64**(2), 139-152. https://doi.org/10.1006/jema.2001.0515.

Duan, J., Chen, Y., Fang, W. and Su, Z. (2015), "Characteristics and relationship of PM, PM10, PM2.5 concentration in a polluted city in Northern China", *Proc. Eng.*, **102**, 1150-1155. https://doi.org/10.1016/j.proeng.2015.01.239.

EEA (2019), "Air pollution sources", *European Environment Agency*, Copenhagen, Denmark. https://www.eea.europa.eu/themes/air/air-pollution-sources-1.

European Commission (2019), "Air quality standards", *European Commission*, Brussels, Belgium. https://ec.europa.eu/environment/air/quality/standards.htm.

Fang, Y., Naik, V., Horowitz, L.W. and Mauzerall, D.L. (2013), "Air pollution and associated human mortality: The role of air pollutant emissions, climate change and methane concentration increases from the preindustrial period to present", *Atmos. Chem. Phys.*, **13**(3), 1377-1394. https://doi.org/10.5194/acp-13-1377-2013.

Gao, M., Guttikunda, S.K., Carmichael, G.R., Wang, Y., Liu, Z., Stanier, C.O., Saide, P.E. and Yu, M. (2015), "Health impacts and economic losses assessment of the 2013 severe haze event in Beijing area", *Sci. Total Environ.*, **511**, 553-561. https://doi.org/10.1016/j.scitotenv.2015.01.005.

Giannadaki, D., Giannakis, E., Pozzer, A. and Lelieveld, J. (2018), "Estimating health and economic benefits of reductions in air pollution from agriculture", *Sci. Total Environ.*, **622**, 1304-1316. https://doi.org/10.1016/j.scitotenv.2017.12.064.

Graff Zivin, J. and Neidell, M. (2011), "The impact of pollution on worker productivity", *Nber Working Paper Series*, **2011**, 17004. https://doi.org/10.3386/w17004.

Hanna, R. and Oliva, P. (2015), “The effect of pollution on labor supply: Evidence from a natural experiment in Mexico city”, *J. Public Econ*., **122**, 68-79. https://doi.org/10.1016/j.jpubeco.2014.10.004.

Huang, D., Xu, J. and Zhang, S. (2012), “Valuing the health risks of particulate air pollution in the pearl river delta, China”, *Environ. Sci. Policy*, **15**(1), 38-47. https://doi.org/10.1016/j.envsci.2011.09.007.

Huang, D.S, and Zhang, S. (2013), “Health benefit evaluation for PM2.5 pollution control in Beijing-Tianjin-Hebei region of China”, *Zhongguo Huanjing Kexue/China Environ. Sci*., **33**, 166-174.

Hunt, A., Ferguson, J., Hurley, F. and Searl, A. (2016), “Social costs of morbidity impacts of air pollution”, *OECD Work. Papers*, **99**, 78.

Jiang, N., Yin, S., Guo, Y., Li, J., Kang, P., Zhang, R. and Tang, X. (2018), “Characteristics of mass concentration, chemical composition, source apportionment of PM2.5 and PM10 and health risk assessment in the emerging megacity in China”, *Atmos. Pollut. Res*., **9**(2), 309-321. https://doi.org/10.1016/j.apr.2017.07.005.

Kan, H. and Chen, B. (2004), “Particulate air pollution in urban areas of Shanghai, China: Health-based economic assessment”, *Sci. Total Environ*., **322**(1-3), 71-79. https://doi.org/10.1016/j.scitotenv.2003.09.010.

Kazhydromet (2018), *Informational Bulletin on the State of Environment in the Republic of Kazakhstan*, Kazakhstan.

Kenessariyev, U., Golub, A., Brody, M., Dosmukhametov, A., Amrin, M., Erzhanova, A. and Kenessary, D. (2013), “Human health cost of air pollution in Kazakhstan”, *J. Environ. Protect*., **4**(8), 869-876. http://doi.org/10.4236/jep.2013.48101.

Kenessary, D., Kenessary, A., Adilgireiuly, Z., Akzholova, N., Erzhanova, A., Dosmukhametov, A., Syzdykov, D., Masoud, A. and Saliev, T. (2019), “Air pollution in Kazakhstan and its health risk assessment”, *Annal. Global Health*, **85**(1), 133. https://doi.org/10.5334/aogh.2535.

Kerimray, A., Azbanbayev, E., Kenessov, B., Plotitsyn, P., Alimbayeva, D. and Karaca, F. (2020), “Spatiotemporal variations and contributing factors of air pollutants in Almaty, Kazakhstan”, *Aerosol Air Quality Res*., **20**(6), 1340-1352. https://doi.org/10.4209/aaqr.2019.09.0464.

Kerimray, A., Tokazhanov, G., Ramazanova, E. and Lee, W. (2018), *Analysis of Historical Trends of Air Pollutants Concentrations in the Cities of Kazakhstan and Assessment of Their Future Concentrations Estimated until 2050 According to “Business as Usual” and “OECD Standards” Scenario,* National Laboratory Astana, Kazakhstan.

Kerimray, A., Baimatova, N., Ibragimova, O.P., Bukenov, B., Kenessov, B., Plotitsyn, P. and Karaca, F. (2020), “Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan”, *Sci. Total Environ*., **730**, 139179. https://doi.org/10.1016/j.scitotenv.2020.139179.

Kim, K.H., Kabir, E. and Kabir, S. (2015), “A review on the human health impact of airborne particulate matter”, *Environ. Int*., **74**, 136-143. http://doi.org/10.1016/j.envint.2014.10.005.

Kumar, P., Skouloudis, A.N., Bell, M., Viana, M., Carotta, M.C., Biskos, G. and Morawska, L. (2016), “Real-time sensors for indoor air monitoring and challenges ahead in deploying them to urban buildings”, *Sci. Total Environ*., **560**, 150-159. https://doi.org/10.1016/j.scitotenv.2016.04.032.

Li, T. and Lin, G. (2014), “Examining the role of location-specific associations between ambient air pollutants and adult asthma in the United States”, *Health Place*, **25**, 26-33. http://doi.org/10.1016/j.healthplace.2013.10.007.

Long, J. (2020), “Nur-Sultan: A new city for a new era in Kazakhstan”, *Astana Times*, Kazakhstan.

López-Aparicio, S., Guerreiro, C., Viana, M., Reche, C. and Querol, X. (2013), “Contribution of agriculture to air quality problems in cities and in rural areas in Europe”, ETC/ACM, **10**, 2013.

Lucarelli, F., Barrera, V., Becagli, S., Chiari, M., Giannoni, M., Nava, S., Traversi, R. and Calzolai, G. (2019), “Combined use of daily and hourly data sets for the source apportionment of particulate matter near a waste incinerator plant”, *Environ. Pollut*., **247**, 802-811. https://doi.org/10.1016/j.envpol.2018.11.107.

Meister, K., Johansson, C. and Forsberg, B. (2012), “Estimated short-term effects of coarse particles on daily mortality in Stockholm, Sweden", *Environ. Health Perspect.*, **120**(3), 431-436. https://doi.org/10.1289/ehp.1103995.

Núñez-Alonso, D., Pérez-Arribas, L.V., Manzoor, S. and Cáceres, J.O. (2019), "Statistical tools for air pollution assessment: Multivariate and spatial analysis studies in the Madrid region", *J. Anal. Methods Chem.*, **2019**, 9753927. https://doi.org/10.1155/2019/9753927.

OECD (2014), *The Cost of Air Pollution*, Organisation for Economic Co-operation and Development, Paris, France.

OECD (2016), *The Economic Consequences of Outdoor Air Pollution*, Organisation for Economic Co-operation and Development, Paris, France.

365 Info.kz. (2014), К 2030 Году в Атырау Ожидается Рост Населения [Population Growth is Expected by 2030 in Atyrau], 365 Info.kz., Kazakhstan. https://365info.kz/2014/11/k-2030-godu-v-atyrau-ozhidaetsya-rost-naseleniya.

Ostro, B. (2004), *Outdoor Air Pollution: Assessing the Environmental Burden of Disease at National and Local Levels*, WHO, Geneva.

Perera, F., Berberian, A., Cooley, D., Shenaut, E., Olmstead, H., Ross, Z. and Matte, T. (2021), "Health benefits of sustained air quality improvements in New York city: A simulation based on air pollution levels during the COVID-19 shutdown", *Environ. Res.*, **193**, 110555. https://doi.org/10.1016/j.envres.2020.110555.

Pervin, T., Gerdtham, U.G. and Lyttkens, C.H. (2008), "Societal costs of air pollution-related health hazards: A review of methods and results", *Cost Eff. Resour. Alloc.*, **6**, 19. https://doi.org/10.1186/1478-7547-6-19.

Pimpin, L., Retat, L., Fecht, D., de Preux, L., Sassi, F., Gulliver, J., Belloni, A., Ferguson, B., Corbould, E., Jaccard, A. and Webber, L. (2018), "Estimating the costs of air pollution to the national health service and social care: An assessment and forecast up to 2035", *PLOS Med.*, **15**(7), e1002602. https://doi.org/10.1371/journal.pmed.1002602.

Pope, C.A., Dockery, D.W. and Schwartz, J. (1995), "Review of epidemiological evidence of health effects of particulate air pollution", *Inhal. Toxicol.*, **7**(1), 1-18. https://doi.org/10.3109/08958379509014267.

Saramak, A. (2019), "Comparative analysis of indoor and outdoor concentration of PM10 particulate matter on example of Cracow city center", *Int. J. Environ. Sci. Technol.*, **16**(11), 6609-6616. https://doi.org/10.1007/s13762-019-02250-5.

Shah, A.S., Langrish, J.P., Nair, H., McAllister, D.A., Hunter, A.L., Donaldson, K., Newby, D.E. and Mills, N.L. (2013), "Global association of air pollution and heart failure: A systematic review and meta-analysis", *Lancet*, **382**(9897), 1039-1048. http://doi.org/10.1016/S0140-6736(13)60898-3.

Sun, R., Zhou, Y., Wu, J. and Gong, Z. (2019), "Influencing factors of PM2.5 pollution: Disaster points of meteorological factors", *Int. J. Environ. Res. Public Health*, **16**(20), 3891. https://doi.org/10.3390/ijerph16203891.

Syzdykbaev, A. (2016), "By 2050 GDP per capita will Grow 4.5 times - Kazakh president", *Kazpravda*, Kazakhstan.

Torkmahalleh, M.A., Hopke, P.K., Broomandi, P., Naseri, M., Abdrakhmanov, T., Ishanov, A., Kim, J. Shah, D. and Kumar, P. (2020), "Exposure to particulate matter and gaseous pollutants during cab commuting in Nur-Sultan city of Kazakhstan", *Atmos. Pollut. Res.*, **11**(5), 880-885. https://doi.org/10.1016/j.apr.2020.01.016.

UNDESA (2017), *Changing Population Age Structures and Sustainable Development: A Concise Report*, Department of Economic and Social Affairs, UNDESA, New York, U.S.A.

Moi Gorod (2019), Жителей Уральска Стало Больше - Новости Уральска, Актобе, Атырау [The number of Uralsk residents has increased - News from Uralsk, Aktobe, Atyrau], Moi Gorod, Kazakhstan. https://mgorod.kz/nitem/zhitelej-uralska-stalo-bolshe.

Vardoulakis, S. and Kassomenos, P. (2008), "Sources and factors affecting PM10 levels in two European cities: Implications for local air quality management", *Atmos. Environ.*, **42**(17), 3949-3963. https://doi.org/10.1016/j.atmosenv.2006.12.021.

Vinnikov, D., Tulekov, Z. and Raushanova, A. (2020), "Occupational exposure to particulate matter from air pollution in the outdoor workplaces in almaty during the cold season", *PLoS ONE*, **15**(1), 1-14. https://doi.org/10.1371/journal.pone.0227447.

Wenbo, Z. and Shiqiu, Z. (2010), "Economic valuation of health impact of PM10 pollution in Beijing from 2001 to 2006", *Chinese J. Popul. Resour. Environ.* **8**(2), 68-74. https://doi.org/10.1080/10042857.2010.10684979.

WHO (2009), *Country Profiles of Environmental Burden of Disease, Kazakhstan*, World Health Organization, Geneva, Switzerland.

WHO (2018), *Ambient (Outdoor) Air Pollution*, World Health Organization, Geneva, Switzerland.

World Bank (2012), *Improving Industrial Competitiveness through Potential of Cleaner and Greener Production*, Washington, U.S.A.

Wu, R., Dai, H., Geng, Y., Xie, Y., Masui, T., Liu, Z. and Qian, Y. (2017), "Economic impacts from PM2.5 pollution-related health effects: A case study in Shanghai", *Environ. Sci. Technol.*, **51**(9), 5035-5042. https://doi.org/10.1021/acs.est.7b00026.

Wu, Y., Li, R., Cui, L., Meng, Y., Cheng, H. and Fu, H. (2020), "The high-resolution estimation of sulfur dioxide ($SO_2$) concentration, health effect and monetary costs in Beijing", *Chemosphere*, **241**, 125031. https://doi.org/10.1016/j.chemosphere.2019.125031.

Xu, G., Jiao, L., Zhang, B., Zhao, S., Yuan, M., Gu, Y., Liu, J. and Tang, X. (2017), "Spatial and temporal variability of the PM2.5/PM10 ratio in Wuhan, Central China", *Aerosol Air Qual. Res.*, **17**(3), 741-751. https://doi.org/10.4209/aaqr.2016.09.0406.

Xu, W., Zeng, Z., Xu, Z., Li, X., Chen, X., Li, X., Xio, R., Liang, J., Chen, G., Lin, A., Li, J. and Zeng, G. (2020), "Public health benefits of optimizing urban industrial land layout - the case of Changsha, China", *Environ. Pollut.*, **263**, 114388. https://doi.org/10.1016/j.envpol.2020.114388.

Yang, Y., Ruan, Z., Wang, X., Yang, Y., Mason, T G., Lin, H. and Tian, L. (2019), "Short-term and long-term exposures to fine particulate matter constituents and health: A systematic review and meta-analysis", *Environ. Pollut.*, **247**, 874-882. https://doi.org/10.1016/j.envpol.2018.12.060.

Zanobetti, A., Schwartz, J. and Dockery, D.W. (2000), "Airborne particles are a risk factor for hospital admissions for heart and lung disease", *Environ. Health Perspect.*, **108**(11), 1071-1077. https://doi.org/10.1289/ehp.001081071.

Zhang, D., Aunan, K., Seip, H.M., Larssen, S., Liu, J. and Zhang, D. (2010), "The assessment of health damage caused by air pollution and its implication for policy making in Taiyuan, Shanxi, China", *Energy Policy*, **38**(1), 491-502. https://doi.org/10.1016/j.enpol.2009.09.039.

Zhao, D., Chen, H., Yu, E. and Luo, T. (2019), "PM 2.5 /PM 10 ratios in eight economic regions and their relationship with meteorology in China", *Adv. Meteorol.*, **2019**, 5295726. https://doi.org/10.1155/2019/5295726.

Zhusupova, A. and Kenesov, A. (2012), "Внутренние Мигранты и Современный Казахстан [Internal Migrants and Modern Kazakhstan]", *Вестник КазНУ*, **3**(40), 44-47.

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## Appendix

Fig. S1 Cities of Kazakhstan analyzed in the study

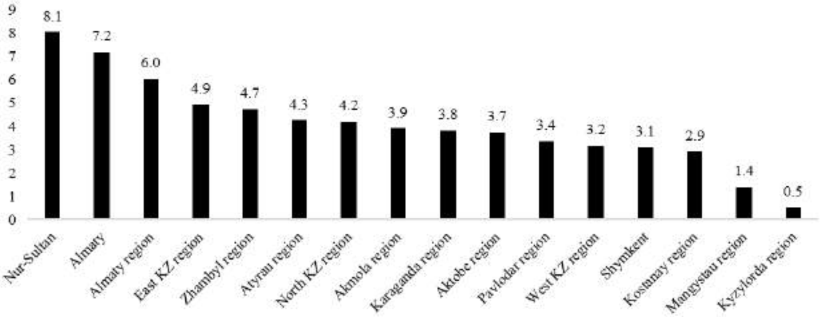

Fig. S2 Region rating by average annual GRP growth for the period of 2011-2017 (Committee on Statistics 2018)

In 2017, Shymkent was a part of South Kazakhstan region but now it is separate city. GRP value demonstrated here accounts for modern Shymkent city and Turkestan region together.

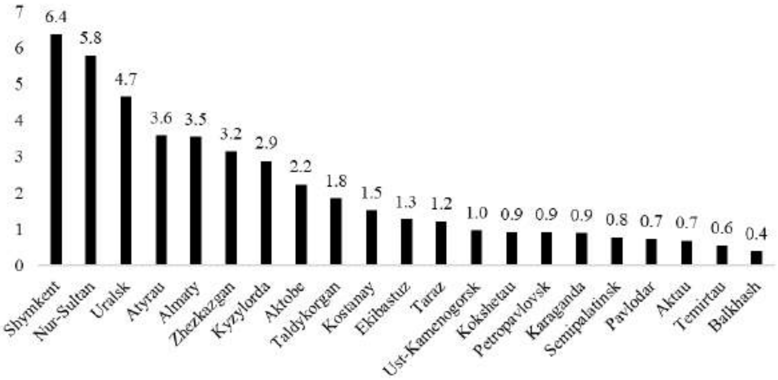

Fig. S3 City rating by average annual population growth for the period of 2011-2017 (Committee on Statistics 2018)

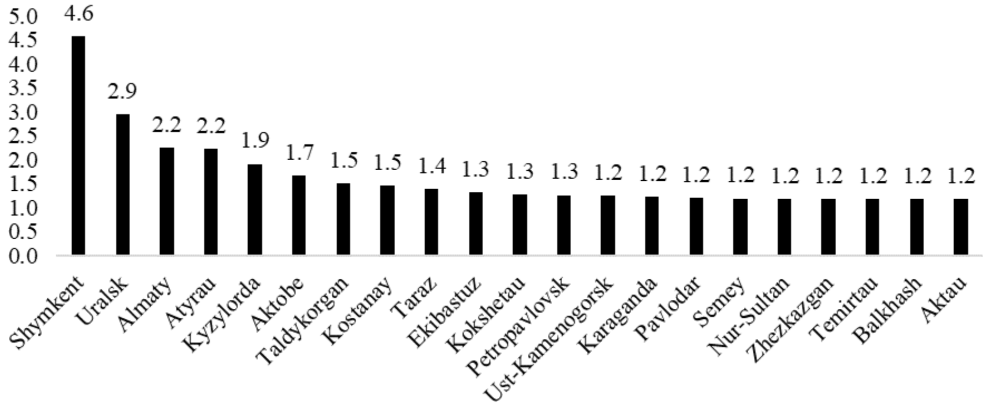

Fig. S4 Forecast values for the population in 2050 compared to 2017

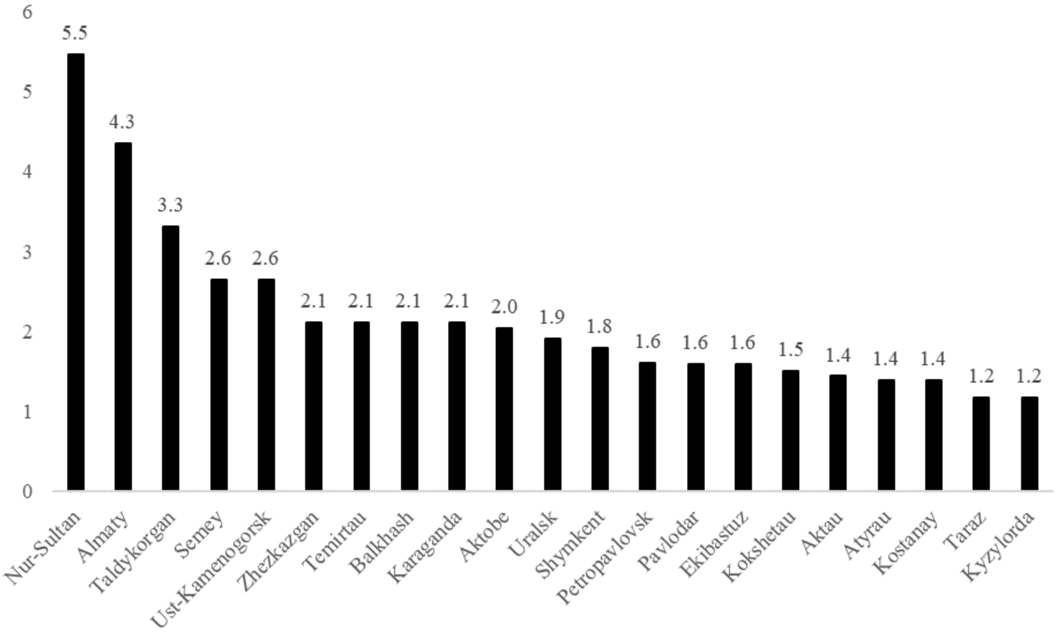

Fig. S5 Forecast values for the gross regional product (GRP) in 2050 compared to 2017

Table S1 Location of observation posts

| City | Frequency | Type of sampling | Location |
|---|---|---|---|
| Nur-Sultan | 3 times/day | Manual | Dzhambul st. 211 |
| | 3 times/day | Manual | Auezov-Seyfullin st. intersection |
| | 3 times/day | Manual | Tashkent st., Lesozavod area |
| | 3 times/day | Manual | Valikhanov st.-Bogembay Batyr ave. intersection, “Shapagat” market |
| Zhezkazgan | 3 times/day | Manual | Saryarka st., knitwear fabric area |
| | 3 times/day | Manual | Zhastar st. 6, Mettalurg square |

Table S1 Continued

| | | | |
|---|---|---|---|
| Temirtau | 3 times/day | Manual | Dmitrov st. 212 |
| | 3 times/day | Manual | 6th district “Amangeldy”/ Temirtau st. |
| | 3 times/day | Manual | 3a district (near emergency station) |
| Shymkent | 3 times/day | Manual | Abay ave., JSC “Yuzhpolymetal” |
| | 3 times/day | Manual | Ordabassy square, Kazybek bi st. and Tole bi st. intersection |
| | 3 times/day | Manual | Aldiyarov st. 6, JSC “Shymkentcement” |
| | 3 times/day | Manual | Sairam st. 198, near brewery |
| Balkhash | 3 times/day | Manual | Sabitov district (near School #6) |
| | 3 times/day | Manual | Lenin st. and Alimzhanov st. intersection |
| | 3 times/day | Manual | Kirov st. (near hospital) |
| Almaty | 4 times/day | Manual | Amangeldy st. and Satpayev st. intersection |
| | 3 times/day | Manual | Rayimbek ave. and Nauryzbay batyr st. intersection |
| | 3 times/day | Manual | Ainabulak disctrict 3 |
| | 3 times/day | Manual | Marechek st. and Momyshuly st. intersection |
| | 3 times/day | Manual | Tastak district 1, Tole bi st. 249 |
| Aktau | 3 times/day | Manual | 1st district, Caspian department of ecology |
| | 3 times/day | Manual | Aktau seaport |
| Atyrau | 3 times/day | Manual | Azattyq ave. and Auezov ave. intersection |
| | 3 times/day | Manual | Satpayev ave. and Vladimirskaya st. intersection |
| Taraz | 3 times/day | Manual | Shhymkent st. 22 |
| | 3 times/day | Manual | Rysbek batyr st. 15 and Niyetkaliyev st. intersection |
| | 3 times/day | Manual | Abay st. and Tolebi st. intersection |
| | 3 times/day | Manual | Bayzak batyr st. 162 |
| Pavlodar | 3 times/day | Manual | Kamzinn st. and Chkalov st. intersection |
| | 3 times/day | Manual | Aimanov st. 26 |
| Ekibastuz | 3 times/day | Manual | Berkembayev st and Satpayev st. intersection, 8th disctrict |
| Karaganda | 4 times/day | Manual | Airport area |
| | 3 times/day | Manual | Lenin st. and Bukhar Zhyrau ave. 1 intersection |
| | 3 times/day | Manual | Biryzov st. 15 |
| | 3 times/day | Manual | Ermekov st. 116 |
| Semey | 3 times/day | Manual | Ryskulov st. and Glinka st. intersection |
| | 3 times/day | Manual | 343th district (kindergarden) |
| Ust-Kamenogorsk | 3 times/day | Manual | Rabochaya st. 6 |
| | 3 times/day | Manual | Kaysenov st. 30 |
| | 3 times/day | Manual | 1st October st. 126 |
| | 3 times/day | Manual | Egorov st. 6 |
| | 3 times/day | Manual | Satpayev ave. 12 |
| Taldykorgan | 3 times/day | Manual | Gagarin st. 216 and Zhabayev st. intersection |
| Kokshetau | 3 times/day | Manual | Meteostation |

Table S1 Continued

| | | | |
|---|---|---|---|
| Petropavlovsk | 3 times/day | Manual | Valikhanov st. 17 |
| | 3 times/day | Manual | Buketov st. 16 and Kazpravda st. intersection |
| Uralsk | every 20 min | Automatic | Gagarin st. 25 |
| | every 20 min | Automatic | Daumov st. (near Kirov park) |
| | every 20 min | Automatic | Muhit st. (Mirlan market) |
| Kyzylorda | 3 times/day | Manual | Muratbayev st. 24-a |
| Aktobe | 4 times/day | Manual | Aviagorodok 14 |
| | 3 times/day | Manual | Belinskii st. 5 |
| | 3 times/day | Manual | Lmonosov st. 7 |
| Kostanay | 3 times/day | Manual | Kairbekov st. 379 |
| | 3 times/day | Manual | Doschanov st. 43 |
| | every 20 min | Automatic | Borodin st. |
| | every 20 min | Automatic | Mayakovskii st. |

Table S2 Predicted concentrations of $PM_{10}$ in the OECD Standards scenario, µg/m$^3$

| City | 2017[1] | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Astana | 138 | 105 | 73 | 40 | 40 | 40 | 40 | 40 |
| Zhezkazgan | 135 | 104 | 72 | 40 | 40 | 40 | 40 | 40 |
| Temirtau | 131 | 101 | 70 | 40 | 40 | 40 | 40 | 40 |
| Shymkent | 103 | 82 | 61 | 40 | 40 | 40 | 40 | 40 |
| Balkhash | 87 | 71 | 56 | 40 | 40 | 40 | 40 | 40 |
| Almaty | 82 | 68 | 54 | 40 | 40 | 40 | 40 | 40 |
| Aktau | 74 | 63 | 51 | 40 | 40 | 40 | 40 | 40 |
| Atyrau | 64 | 56 | 48 | 40 | 40 | 40 | 40 | 40 |
| Taraz | 62 | 54 | 47 | 40 | 40 | 40 | 40 | 40 |
| Pavlodar | 61 | 54 | 47 | 40 | 37 | 29 | 22 | 13 |
| Ekibastuz | 59 | 53 | 46 | 40 | 40 | 40 | 40 | 40 |
| Karaganda | 54 | 49 | 45 | 40 | 40 | 40 | 40 | 40 |
| Semipalatinsk | 52 | 48 | 44 | 40 | 40 | 40 | 40 | 40 |
| Ust-Kamenogorsk | 45 | 44 | 42 | 40 | 38 | 35 | 32 | 29 |
| Taldykorgan | 42 | 41 | 40 | 39 | 37 | 36 | 34 | 32 |
| Kokshetau | 74 | 63 | 51 | 40 | 40 | 40 | 40 | 40 |
| Petropavlovsk | 28 | 32 | 35 | 39 | 40 | 40 | 40 | 40 |
| Uralsk | 41 | 41 | 40 | 40 | 39 | 38 | 37 | 36 |
| Kyzylorda | 15 | 14 | 13 | 12 | 11 | 9 | 8 | 6 |
| Aktobe | 12 | 12 | 12 | 12 | 11 | 11 | 11 | 11 |
| Kostanai[2] | 48 | 46 | 43 | 40 | 40 | 40 | 40 | 40 |

[1] Average concentration during 2015-2017

[2] Measured value of $PM_{10}$

Table S3 Predicted concentrations of $PM_{2.5}$ in the air up to 2050 according to the “Business as usual” scenario, µg/$m^3$

| City | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Astana | 62.1 | 65.8 | 72.1 | 80.3 | 91.0 | 104.7 | 122.6 | 145.6 |
| Zhezkazgan | 60.9 | 62.4 | 64.8 | 67.5 | 70.5 | 73.9 | 77.7 | 82.0 |
| Temirtau | 58.9 | 61.8 | 66.8 | 72.2 | 78.1 | 84.6 | 91.7 | 99.5 |
| Shymkent | 46.5 | 46.5 | 46.6 | 46.8 | 46.9 | 47.1 | 47.2 | 47.4 |
| Balkhash | 39.0 | 41.5 | 45.8 | 50.6 | 55.9 | 61.9 | 68.6 | 76.2 |
| Almaty | 37.1 | 38.5 | 40.9 | 43.7 | 47.1 | 51.1 | 55.8 | 61.3 |
| Aktau | 33.4 | 32.7 | 31.5 | 30.3 | 29.0 | 27.7 | 26.4 | 25.1 |
| Atyrau | 28.7 | 27.9 | 26.9 | 25.6 | 24.2 | 22.6 | 20.7 | 18.6 |
| Taraz | 27.8 | 27.4 | 26.4 | 25.5 | 24.4 | 23.4 | 22.3 | 21.1 |
| Pavlodar | 27.6 | 25.9 | 22.9 | 19.8 | 16.6 | 13.2 | 9.7 | 6.1 |
| Ekibastuz | 26.5 | 28.8 | 33.1 | 37.7 | 42.7 | 48.0 | 53.8 | 60.0 |
| Karaganda | 24.1 | 27.7 | 31.9 | 36.3 | 41.0 | 46.0 | 51.2 | 56.8 |
| Semipalatinsk | 23.3 | 24.6 | 26.9 | 29.2 | 31.5 | 34.0 | 36.4 | 38.9 |
| Ust-Kamenogorsk | 20.2 | 19.7 | 18.9 | 18.0 | 17.0 | 15.8 | 14.5 | 13.0 |
| Taldykorgan | 19.0 | 18.6 | 18.1 | 17.5 | 16.8 | 16.1 | 15.3 | 14.5 |
| Kokshetau | 33.2 | 37.4 | 43.5 | 49.8 | 56.4 | 63.3 | 70.5 | 78.0 |
| Petropavlovsk | 12.4 | 14.2 | 15.9 | 17.7 | 19.5 | 21.4 | 23.4 | 25.5 |
| Uralsk | 18.4 | 18.3 | 18.0 | 17.8 | 17.5 | 17.2 | 16.8 | 16.4 |
| Kyzylorda | 6.7 | 6.4 | 5.9 | 5.4 | 4.8 | 4.2 | 3.5 | 2.7 |
| Aktobe | 5.5 | 5.5 | 5.4 | 5.3 | 5.2 | 5.0 | 4.9 | 4.8 |
| Kostanay | 62.1 | 65.8 | 72.1 | 80.3 | 91.0 | 104.7 | 122.6 | 145.6 |