The burden of air pollution in Türkiye's cities, 2021

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Key Findings

- **What were the $PM_{2.5}$ concentrations in 2021?**
  The measured 2021 annual mean $PM_{2.5}$ concentrations for each province included in this report range from 10.8 to 34.5 μg/m^3. Across the whole population included in the study the weighted annual mean $PM_{2.5}$ exposure was 20.7 μg/m^3. This concentration is more than four times higher than the Air Quality Guideline recommended by the World Health Organization (WHO).
- **What were the health impacts?**
  It is estimated that long-term exposure to $PM_{2.5}$ in the cities and provinces included in this study contributed to 34,000 premature deaths during 2021. Had $PM_{2.5}$ concentrations in these locations met the WHO guideline, the number of premature deaths attributable to $PM_{2.5}$ pollution could have been reduced by 75%, saving an estimated 26,000 lives each year.
- **How do the death numbers compare to car crashes etc?**
  Across the cities included in this report, there were an estimated 34,000 premature deaths attributable to $PM_{2.5}$ exposure in 2021. This translates to a fatality rate of approximately 64 per 100,000 people. This rate is many times higher than the combined rates for road accidents, drug use and intentional homicide across Türkiye.
- **What should be done about it?**
  Türkiye should immediately define annual average and 24-hour average limit values for $PM_{2.5}$ mass concentration. These limit values must be set out in national regulations with legally binding target dates by which the limit must be achieved. Limit values should, as a minimum, be aligned with the levels that protect the health of EU citizens. Greater protection would be achieved by aligning with the updated guidelines of the World Health Organization, and Türkiye is encouraged to adopt these levels for the benefit of public health. Regions with $PM_{2.5}$ pollution breaching national regulations must be declared 'Protection Zones' where measures are introduced to improve air quality including through the suspension or closure of polluting industries.
  Air pollution and the climate crisis are closely linked. These measures could hasten a transition to renewable energy technology and clean transport systems, bringing significant financial, environmental and health co-benefits.

Contents

Introduction

Exposure to air pollution increases morbidity, shortens life expectancy and is a major global public health risk. This report uses ground level monitoring data in locations across Türkiye to estimate the number of premature deaths that can be attributed to fine particulate matter air pollution ($PM_{2.5}$, see Box 1). Long-term exposure to $PM_{2.5}$ pollution is considered in 38 cities and provinces across Türkiye including Istanbul and Ankara. Only those provinces for which $PM_{2.5}$ data are available are included, these areas are home to over 60% of Türkiye's population. Comparison is also made against four major city regions, New York, Delhi, Kuala Lumpur and Seoul.

In 2019 the Global Burden of Disease study described long-term exposure to fine particulate matter air pollution as the largest environmental risk factor for human health (GBD, 2019). Globally, the risk of mortality posed by air pollution is of similar magnitude to that from unhealthy diets and even smoking (WHO, 2021). The wider implications of air pollution for our society and the economy include increased medical costs, and reduced productivity through lost working days (HRAPIE, 2013).

Advances in air pollution and epidemiology research in recent decades mean that it is now possible to calculate the risk of premature mortality posed by air pollution, and to estimate the number of premature deaths attributable to that air pollution that might occur. For example, computer modelling has previously projected that in 2012, 12% of all the deaths of Turkish people from across the country aged 14 and older could be attributed to long term exposure to $PM_{2.5}$ from fossil-fuel combustion (Vohra et al., 2021).

Of the $PM_{2.5}$ emissions reported by Türkiye to the European Environment agency in 2019 54% were related to commercial and residential emissions, 30% to extractive industry and manufacturing, 11% to energy supply and the remainder to sectors including transport, agriculture and waste (EEA, 2021).

The air pollution problems facing society today are closely linked to the climate crisis through a common cause, the emission of pollutants into the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) reported in 2022 that a substantial reduction in fossil fuel use is required to reduce emission of greenhouse gases and air pollutants, and that because the cost of low-emission energy has dramatically reduced it can now be more costly to maintain emission-intensive infrastructure than to transition to renewable energy (IPCC, 2022).

The close links between our health, environment and economy are explored in this report, which finds that a transition to renewable energy technology and clean transport systems could bring significant financial, environmental and health co-benefits.

Box 1: What is $PM_{2.5}$?

Particulate matter is pollution in the form of small liquid or solid particles suspended in the atmosphere. PM pollution is described according to the size of the particles, rather than the chemicals within them. $PM_{2.5}$ refers to any particle that is less than 2.5 micrometers across; it is sometimes known as 'fine particulate matter' or 'fine suspended particles' (FSP). $PM_{2.5}$ particles are small enough to penetrate deep into the lungs to the gas-exchange region (Morakinyo et al., 2016).

Air quality standards

The World Health Organization (WHO) publishes guidelines for air quality which are designed to protect public health. The WHO Air Quality Guidelines are determined through detailed reviews of the latest scientific research and apply to different air pollutant concentrations over differing averaging periods. Türkiye has national air quality standards for pollutants including PM_{10}, SO_2 and NO_2, however no national air quality standard exists for $PM_{2.5}$ despite overwhelming evidence of its importance for human health. The WHO Guidelines and current local air quality standards for $PM_{2.5}$ are shown in Table 1.

Table 1: The World Health Organization Air Quality Guidelines for 24-hour and annual average concentrations of $PM_{2.5}$.

Standard	Annual mean $PM_{2.5}$ concentration (μg/m^3)
National Standard*	-
WHO Guideline	5

Source: WHO (2021)

*No national air quality standard exists for $PM_{2.5}$.

Methods

The number of premature deaths that can be attributed to long-term $PM_{2.5}$ exposure are estimated using ground-level air quality measurements for 2021. The measured annual average concentrations of $PM_{2.5}$ are combined with population for each location and country-wide public health data for Türkiye. Scientific risk models are then applied to the data in order to quantitatively estimate the health costs of exposure to $PM_{2.5}$ air pollution in each location. In addition to the actual measured $PM_{2.5}$ exposure, a further scenario is examined in order to estimate the potential health benefit from improving air quality in Türkiye to meet the WHO Guideline for annual mean $PM_{2.5}$ (Table 2).

This report only assesses premature mortality. Only those causes of mortality where robustly quantifiable relationships with air pollution have been established in the literature and where epidemiological data are available for Turkey in the Global Burden of Disease (GBD, 2019) catalogue are included (Table 3). Many more health impacts can be attributed to $PM_{2.5}$ exposure, including non-lethal health outcomes such as low birth weight (Dadvand et al., 2013), preterm birth (Trasande et al., 2016), increase in asthma symptoms (HRAPIE, 2013), increase in hospital admissions and emergency room visits due to asthma (Zheng et al., 2015), and mental health issues (Braithwaite et al., 2019).

Table 2: Scenarios

Scenario	Description	Description
A	2021 Actual	Assessment of premature deaths attributable to $PM_{2.5}$ exposure **for measured annual mean $PM_{2.5}$ concentrations during 2021**
B	WHO Guideline	Assessment of premature deaths attributable to annual mean $PM_{2.5}$ exposure **had the WHO Guideline been achieved in all places.**

Ground-level Air Quality Measurements

The analysis uses measured annual and monthly mean $PM_{2.5}$ observations in Türkiye aggregated by location from IQAir and published in their *2021 World Air Quality Report* (IQAir, 2021). The data include that from governmental and regulatory monitoring stations, as well as non-regulatory stations operated by individuals, educational institutions, and non-profit organisations. Combining different data sources provides a uniquely extensive $PM_{2.5}$ dataset.

Monitors operated by non-governmental organisations and individuals underwent quality checks by IQAir before being included in the *2021 World Air Quality Report* (IQAir, 2021). Photo submissions are used to verify that the sensor is in a suitable, sheltered, outdoor location. IQAir continuously checks that the carbon-dioxide (CO_2) concentration, humidity and temperature readings reflect outdoor conditions during operation. The data are also screened for outlying data points when compared with neighbouring monitoring stations during IQAir's quality assurance checks (IQAir, private communication).

The measurements from individual monitoring stations are grouped by the province in which they are located. IQAir uses the average of each individual station within the same province to determine an annual mean $PM_{2.5}$ concentration for that province. This provides an approximation of the province-wide annual average $PM_{2.5}$ concentration. The distribution of monitors within each province is not considered and if the monitors are preferentially located in heavily or lightly polluted areas the $PM_{2.5}$ concentration calculated may over or under-estimate the true province wide average. However, since monitors are usually located where people live, we assume that the data provide a good approximation for the population's average exposure.

Real-world air pollution datasets are rarely complete. Outages during maintenance and technical faults result in missing data. To ensure that systematic bias resulting from diurnal or seasonal patterns in $PM_{2.5}$ concentration are minimised, data are only included where observations are available for at least 90% of the hours and on at least 90% of days during 2021.

Health Impact Assessment

Premature deaths resulting from exposure to $PM_{2.5}$ are assessed for the two pollution scenarios listed in Table 2. The following causes of mortality are included: premature mortality from all causes and a breakdown by a selection of specific causes, namely stroke and other cerebrovascular diseases (CeVD), diabetes, ischaemic heart disease (IHD), lung cancer (LC), lower respiratory infections (LRI) and chronic obstructive pulmonary disease (COPD).

Incidence rates for deaths by these causes for Türkiye, and – for comparison – for New York state, India, Malaysia and South Korea are taken from the Global Burden of Disease catalogue (GBD, 2019).

Risk functions are used to estimate the incidence of premature mortality attributable to $PM_{2.5}$ pollution at a given concentration. Table 4 shows the relative risk for a 10 $\mu g/m^3$ increase in annual mean $PM_{2.5}$ concentration. Risk ratios and incidence rates are combined with the population number of each location as recorded by Türkiye's Address Based Population Registration System (Turkish Statistical Institute, 2022) to convert death rates to absolute death numbers per province.

Population data for each of the four reference cities is adopted from IQAir (2021).

The actual incidence *N* of each cause of mortality is estimated for each province using the location's population *P* and national (or state, for New York) incidence rate n_a.

$$N = P \times n_a$$

The relative risk *RR* of each cause of mortality for a given increase in annual mean $PM_{2.5}$ concentration is estimated using the risk ratio r_0 (relative risk at 10 μg/m^3 increase) and pollutant concentration, c.

$$RR = r_0^{(c/c_0)},$$

with c_0=10 μg/m^3. The incidence of each cause of mortality for a hypothetical scenario with completely clean air is estimated by,

$$N_0 = \frac{N}{RR}$$

The incidence attributable to the measured annual mean $PM_{2.5}$ concentration can therefore be calculated by subtracting the actual incidence and that which is estimated to occur in the clean air scenario. To estimate the incidence for each subsequent scenario where different $PM_{2.5}$ concentrations c_S are achieved, N_s, the incidence in clean air is related to the relative risk by

$$N_s = N_0 \times \left(r_0^{(c_S/c_0)} - 1\right).$$

In places where a scenario's goal was already achieved in 2021, the actual measured annual mean $PM_{2.5}$ concentration is used (i. e. the air quality was not worsened in any of the scenarios).

Uncertainty

The premature mortality figures presented here represent useful estimates of the real-world effect of air pollution based on currently available scientific knowledge and data. Like all research, the data and method used contain uncertainty. This uncertainty relates to the precision and representativeness of pollution measurement data, demographic and epidemiological data. Scientific understanding of the relation between exposure to air pollution and the associated risks for health is an active area of research. The estimates account only for long-term exposure to $PM_{2.5}$ and not for other air pollutants which are also known to have negative health impacts.

Pollutants such as nitrogen dioxide (NO_2), ozone (O_3) and sulphur-dioxide (SO_2) typically have poorer data availability than $PM_{2.5}$. Furthermore, health impacts from reactive species such as NO_2 are not included in our results because these pollutants tend to have high spatial variability and thus the data from point measurements are less representative for the whole province.

The uncertainty associated with the risk ratios and background incidence rates are presented in Tables 3 and 4.

Table 3. Relative uncertainties in the background incidence rates **(1/100,000/year)** used in the health impact assessment.

Location	Risk factor	Incidence per 100,000 (95%-confidence interval)					
		central	low	high	downward uncertainty	upward uncertainty	Name of *cause* in GBD (2019)
Türkiye	**all causes**	**559**	**470**	**660**	**-16%**	**18%**	***All causes***
	CeVD	60	48	73	-20%	22%	*Stroke*
	Diabetes	24	19	29	-20%	22%	*Diabetes mellitus*
	IHD	122	99	149	-19%	22%	*Ischemic heart disease*
	LC	37	29	46	-20%	24%	*Tracheal, bronchus, and lung cancer*
	LRI	18	14	22	-23%	20%	*Lower respiratory infections*
	COPD	36	24	44	-33%	24%	*Chronic obstructive pulmonary disease*
New York City	**all causes**	**844**	**731**	**963**	**-13%**	**14%**	***All causes***
Delhi		**675**	**606**	**750**	**-10%**	**11%**	
Seoul		**597**	**576**	**618**	**-3%**	**4%**	
Kuala Lumpur		**562**	**463**	**679**	**-18%**	**21%**	

Table 4. Risk ratios (RRs) and their relative uncertainty used for the health impact assessment, for a 10 μg/m^3 change in annual average pollutant concentration. Uncertainties are not given for *RR* itself but for *RR* - 1, since that is the deviation from zero-effect (*RR* = 1).

	Value central	Value low	Value high	Source	Downward uncertainty	Upward uncertainty
premature death (all causes)	**1.062**	1.040	1.083	HRAPIE 2013	-35%	34%
premature death (CeVD)	**1.110**	1.050	1.170	Pope 2015	-55%	55%
premature death (diabetes)	**1.130**	1.020	1.260	Pope 2015	-85%	100%
premature death (IHD)	**1.140**	1.100	1.180	Pope 2015	-29%	29%
premature death (LC)	**1.142**	1.057	1.234	Krewski 2009	-60%	65%
premature death (LRI)	**1.120**	1.030	1.300	Mehta 2013	-75%	150%
premature death (COPD)	**1.128**	1.077	1.182	Krewski 2009	-40%	42%

Results

The measured 2021 annual mean $PM_{2.5}$ concentrations for each province included in this report range from 10.8 to 34.5 μg/m^3 (Table 6). The population-weighted annual mean $PM_{2.5}$ concentration was 20.7 μg/m^3. This concentration is more than four times higher than the health based Air Quality Guideline recommended by the WHO (Table 1). Exposure to $PM_{2.5}$ air pollution at these concentrations increases the risk of premature death by about 12% across the study regions.

It is estimated that approximately 34,000 avoidable premature deaths can be attributed to long-term exposure to $PM_{2.5}$ in the Turkish provinces included in this study during 2021. This includes almost 9,000 in Istanbul alone. The risk of premature death from any cause for the population of Istanbul was estimated to be 11% higher than would be the case if the air were completely free from $PM_{2.5}$.

We estimate that 11% of all premature deaths that occured in 2021 in the provinces included in this research can be attributed to exposure to $PM_{2.5}$ pollution. In particular, 18% of premature deaths from stroke and other cerebrovascular diseases, 21% of premature deaths from diabetes, 22% of premature deaths from ischaemic heart disease, 23% of premature deaths from lung cancer, 20% of premature deaths from lower respiratory infections and 21% of premature deaths from COPD are attributable to $PM_{2.5}$ air pollution (Table 6).

The Turkish provinces included in this study failed to meet the WHO guideline for annual mean $PM_{2.5}$ concentrations in 2021. Had they complied with the WHO guideline, this would be expected to have reduced the number of premature deaths attributable to $PM_{2.5}$ pollution to about 8,000 per year, avoiding 75% of the premature deaths and thus preventing approximately 26,000 premature deaths each year (Table 7).

Table 6: Measured annual mean $PM_{2.5}$ concentrations during 2021, associated increase in risk of premature death and number of annual premature deaths attributable to this amount of $PM_{2.5}$ pollution. Totals for $PM_{2.5}$ concentration and increased risk of premature death are population-weighted.

Province	Population	PM2.5 (μg/m3)	Increased risk of premature death	Premature deaths due to PM2.5
Total	*53,199,469*	***20.7***	*+12%*	***34,002***
Istanbul	15,840,900	**17.6**	+11%	**8,895**
Ankara	5,747,325	**17.2**	+11%	**3,157**
Izmir	4,425,789	**17.4**	+11%	**2,458**
Bursa	3,147,818	**26.0**	+17%	**2,547**
Antalya	2,619,832	**19.8**	+13%	**1,644**

Konya	2,277,017	**33.8**	+23%	**2,342**
Adana	2,263,373	**14.5**	+9%	**1,057**
Kayseri	1,434,357	**28.8**	+19%	**1,275**
Samsun	1,371,274	**20.7**	+13%	**897**
Tekirdag	1,113,400	**16.0**	+10%	**571**
Eskisehir	898,369	**15.1**	+10%	**436**
Erzurum	756,893	**34.5**	+23%	**793**
Sivas	636,121	**20.2**	+13%	**407**
Kocaeli	2,033,441	**16.8**	+11%	**1,092**
Balikesir	1,250,610	**14.9**	+9%	**599**
Aksaray	429,069	**19.5**	+12%	**265**
Corum	526,282	**26.7**	+17%	**436**
Sakarya	1,060,876	**22.8**	+15%	**760**
Isparta	445,678	**20.4**	+13%	**288**
Nigde	363,725	**18.2**	+12%	**211**
Bolu	320,014	**15.2**	+10%	**156**
Tokat	602,567	**21.1**	+14%	**401**
Kirikkale	275,968	**19.6**	+13%	**172**
Karaman	258,838	**14.8**	+9%	**123**
Canakkale	557,276	**13.2**	+8%	**238**
Edirne	412,115	**16.0**	+10%	**211**
Zonguldak	589,684	**22.3**	+14%	**414**
Ordu	760,872	**12.9**	+8%	**318**
Bartın	201,711	**22.8**	+15%	**144**
Kirsehir	242,944	**10.8**	+7%	**85**
Amasya	335,331	**28.2**	+18%	**292**
Kastamonu	375,592	**23.2**	+15%	**273**
Yalova	291,001	**15.4**	+10%	**144**
Nevsehir	308,003	**15.6**	+10%	**154**
Igdir	203,159	**66.2**	+49%	**373**
Burdur	273,716	**22.2**	+14%	**191**
Cankiri	196,515	**9.3**	+6%	**60**
Bilecik	228,334	**16.4**	+10%	**120**

Table 7: Results of the Health Impact and Cost Assessment for 2021

	Scenario A	**Scenario B**
	Actual	WHO guideline
premature death	**34,002**	**8,361**

(all causes)		
premature death (CeVD)	6,071	1,450
premature death (diabetes)	2,811	663
premature death (IHD)	15,019	3,523
premature death (LC)	4,576	1,072
premature death (LRI)	1,985	471
premature death (COPD)	4,087	966

The mortality rate that can be attributed to long-term $PM_{2.5}$ exposure in the Turkish provinces studies is 64 deaths per 100,000 people per year. Table 8 puts this into context with risk of death from road accidents, drug use or homicide in the Turkish population as a whole. The risk of death posed by $PM_{2.5}$ on someone living in the study areas is roughly seven times the rate for road traffic fatalities in Türkiye (9.2/100,000 per year) (WHO, 2018). The risk of death from $PM_{2.5}$ in Türkiye is much greater than the combined risk of road accident, drug use or homicide (Figure 1).

Table 8. Cause breakdown of estimated premature deaths.

		Exposed population (millions)	Value	Rate per 100,000	Source
Exposure to $PM_{2.5}$ pollution	Scenario A – actual	53.2	34,002	**63.9**	This report
	Scenario B - WHO guideline	53.2	8,361	**15.7**	
Road accidents		79.5	7,300	**9.2**	WHO (2018)
Drug use		79.5	300	**0.4**	GBD (2019)
Intentional homicide		79.5	2,100	**2.6**	World Bank (2022)
Road accidents, drug use & homicide combined				*12.2*	

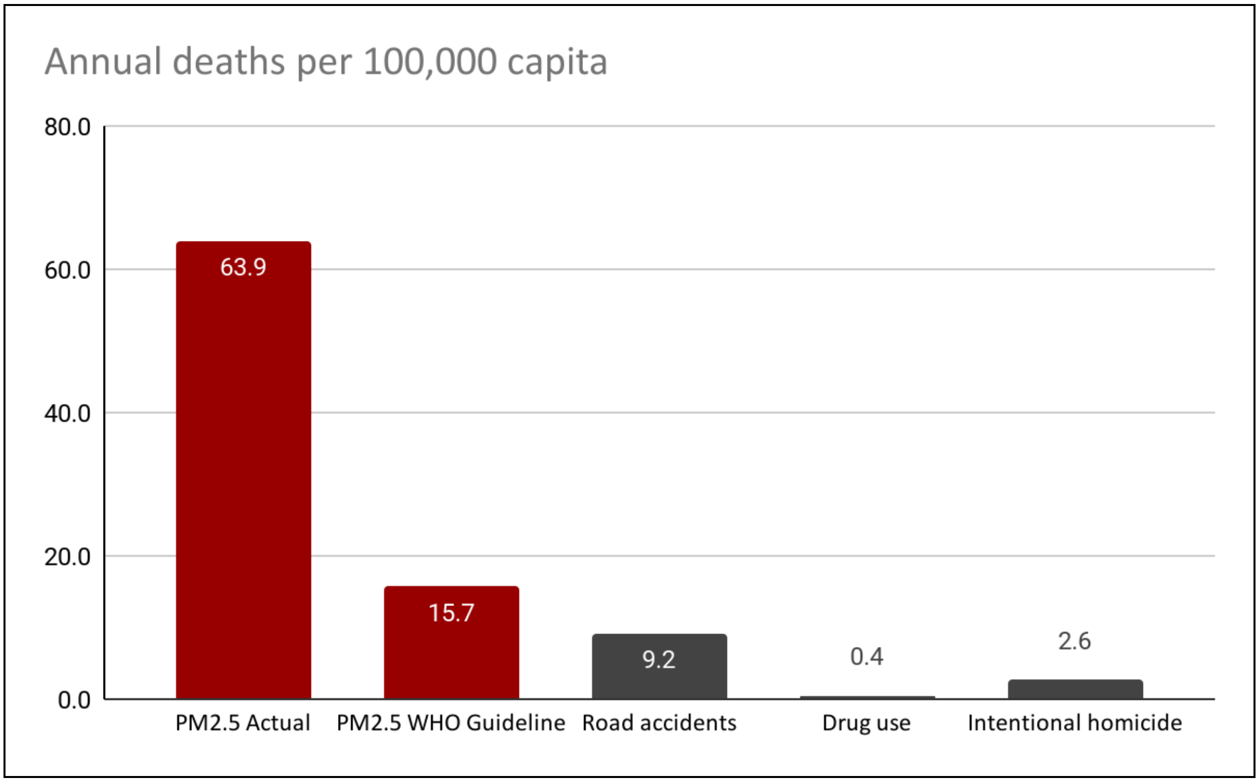

Figure 1. Estimated death rates per 100,000 people during 2021 related to $PM_{2.5}$ and other causes.

A comparison of Istanbul with four other major city regions, New York, Delhi, Seoul and Kuala Lumpur reveals that the risk of premature deaths resulting from long-term $PM_{2.5}$ exposure is lower in Istanbul than in Delhi, and is comparable to that in Seoul and Kuala Lumpur. However New York where $PM_{2.5}$ concentrations in 2021 were lower than those measured in Istanbul the risk of premature death is also lower (Table 9).

Table 9. Comparison with World Cities

City region	Population	$PM_{2.5}$ (μg/m^3)	Increased risk of premature death	Premature deaths due to $PM_{2.5}$
Istanbul	15,840,900	18	+12%	8,895
New York City	18,713,220	10	+6%	9,217
Delhi	29,617,000	96	+79%	88,010
Seoul	21,794,000	20	+13%	14,533
Kuala Lumpur	8,285,000	19	+12%	4,928

Conclusion

There has never been more evidence that air pollution affects health, and can do so even at low concentrations (WHO, 2021). The findings of this study demonstrate that action is urgently needed to address the problem of $PM_{2.5}$ pollution in Türkiye to protect the health of the population.

This year, the IPCC found with high confidence that measures that reduce greenhouse gas and air pollutant emissions including demand reduction, and low emission transport modes have the potential to deliver both air quality improvements and health benefits whilst also contributing to the mitigation of climate change (IPCC, 2022).

Therefore, Türkiye's environment and public health stands to benefit from measures to improve air quality. The effects of $PM_{2.5}$ pollution should be addressed by introducing annual average and 24-hour average limit values for $PM_{2.5}$ mass concentrations. If these limit values are set out in national regulations with legally binding target dates by which the limit must be achieved they should help hasten a transition to renewable energy technology and clean transport systems, bringing significant financial, environmental and health co-benefits.

National limit values should, as a minimum, be aligned with the levels adopted by the EU to protect the health of EU citizens. Greater protection could be achieved by aligning national standards with the recently updated guidelines of the World Health Organization. Türkiye is therefore encouraged to adopt these guidelines for the benefit of public health. Once national standards are established for $PM_{2.5}$, regions with $PM_{2.5}$ pollution breaching those standards could be declared as 'Protection Zones' where measures are introduced to improve air quality including through the suspension or closure of polluting industries.

The health burden from air pollution felt today in Türkiye deserves action to reduce pollutant concentrations, protect public health and encourage sustainable development.

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