Journal of Air Pollution and Health (Autumn 2023); 8(4): 411-424

Original Article

Available online at http://japh.tums.ac.ir

Health impacts assessment and economic costs of implementing three scenarios of the clean air act in one of the largest middle east cities (2017-2026): An AirQ+ modeling

Mozhgan Panji[1], Abbas Shahsavani[1,2,*], Yousef Rashidi[3], Seyed Saeid Hashemi Nazari[4], Anoushiravan Mohseni Bandpei[2], Majid Kermani[5], Zahra Namvar[6]

[1] Department of Environmental Health Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2] Air Quality and Climate Change Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[3] Environmental Sciences Research Institute, Shahid Beheshti University, Tehran, Iran
[4] Safety Promotion and Injury Prevention Research Center, Department of Epidemiology, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5] Research Center for Environmental Health Technology, Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran
[6] Department of Environmental Health Engineering, School of Health, Mazandaran University of Medical Sciences, Sari, Iran

ARTICLE INFORMATION

Article Chronology:
Received 25 September 2023
Revised 11 November 2023
Accepted 05 December 2023
Published 30 December 2023

Keywords:
Clean air law; Economic costs; Health impact assessment; Scenarios; Tehran

CORRESPONDING AUTHOR:

ashahsavani@gmail.com
Tel: (+98 21) 22432040
Fax: (+98 21) 22432037

ABSTRACT

Introduction: This study aimed to assess the health impacts and economic costs of implementing the scenarios of decommissioning end-of-life cars and motorcycles and equipping buses with soot filters in Tehran, one of the largest cities in the Middle East, over a period of ten years (2017-2026) using the AIRQ+ model.

Materials and methods: To start, the emission weights of Particulate matter ($PM_{2.5}$) emitted from the vehicles mentioned in the scenarios were extracted from the Comprehensive National Action Plan for Reducing Air Pollution. Then the concentrations of $PM_{2.5}$ were calculated using AERMOD. Finally, the AIRQ+ model was used to calculate the health effects of the scenarios over ten years.

Results: The results indicated that implementing the total of three scenarios during ten years led to a reduction in mortality rates due to all causes, Chronic Obstructive Pulmonary Disease (COPD), lung cancer, Acute Lower Respiratory tract Infection (ALRI), Ischemic Heart Disease (IHD), and stroke by 14.89%, 6.16%, 31.51%, 19.5%, 16.5%, and 17.38%, respectively. In addition, decommissioning end-of-life cars and motorcycles separately led to a 6.75% and 6.53% reduction in deaths from all causes, 2.54% and 2.46% from COPD, 18.40% and 18.01% from lung cancer, 11.16% and 11% from ALRI, 12.82% and 12.69% from IHD, and 12.12% and 12.96% from stroke.

Conclusion: The results indicate that the implementation of these scenarios during ten years has positive effects on reducing deaths attributed by $PM_{2.5}$ particles, but due to population growth, it has no effect on reducing economic costs.

Introduction

Air pollution is a significant environmental concern in both developed and developing countries, impacting human health and the economy [1]. Chronic exposure to ambient $PM_{2.5}$ (Particulate Matter with an aerodynamic diameter

Please cite this article as: Panji M, Shahsavani A, Rashidi Y, Hashemi Nazari SS, Mohseni Bandpei A, Kermani M, et al. Health impacts assessment and economic costs of implementing three scenarios of the clean air act in one of the largest middle east cities (2017-2026): An AirQ+ modeling. Journal of Air Pollution and Health. 2023;8(4): 411-424.

of less than 2.5 μm) is linked to a lower life expectancy, a loss of healthy life years, and an increase in mortality from cardiovascular and respiratory disorders [2, 3]. Moreover, air pollution has a negative economic impact on governments, such as increasing annual health insurance premiums, medical costs, and rehabilitation expenses [4].

Various factors, such as urbanization, population growth, industrialization, transportation, and inappropriate consumption patterns, have raised concerns about worsening air quality [1, 5]. According to the World Health Organization (WHO), Iranian cities, including Tehran, have some of the highest levels of suspended particles and the concentration of fine particles ($PM_{2.5}$), which for years have been exceeded the WHO's recommended levels [6]. One of the leading contributors to air pollution in Iran is vehicles, the majority of which are over 20 years old [7, 8]. Over 85% of emissions in Tehran Mega-City (TMC) attributed to traffic sources [8]. The rapid growth of vehicles, with a 14.6% annual growth, exacerbates the problem [9].

Over the past few decades, the Iranian government has taken steps to tackle air pollution. One significant measure is the Clean Air Act, which seeks to enhance the nation's air quality through infrastructure enhancements. This includes minimizing or decommissioning end-of-life cars and motorcycles, as well as equipping buses with soot filters [10]. The evaluation of environmental policies plays a crucial role in the decision-making process aimed at assessing the effectiveness of these policies and facilitates the formulation of new policies to succeed in achieving their intended objectives [11]. Therefore, evaluating environmental programs and policies in the country, especially polluted cities, can be a great help in solving problems and providing new methods to reduce pollutants and their negative effects.

There are a number of pakages that can assess the health effects of air pollution, such as AirQ+, BenMAP, etc. Among these models AirQ+ is free and up-to-date WHO developed program. It takes into account both short-term and long-term exposures and has been verified for common air pollutants (BC, NO_2, O_3, PM_{10}, and $PM_{2.5}$) [12]. If the concentration of pollutants is not provided, the AERMOD software can still calculate it using certain prerequisite data. The AERMOD modeling system includes a dispersion model along with AERMET and AERMAP preprocessors. These preprocessors provide the model with meteorological and receiver data, which helps in determining the distribution of pollutant concentration [13].

Before conducting this research, there was no existing information regarding the effects of decommissioning End-of-Life Vehicles (ELVs) on public health and finances in the country. Therefore, using the AIRQ+ model, this study aims to assess the health effects and economic costs of reducing $PM_{2.5}$ emissions decommissioning end-of-life cars and motorcycles and equipping buses with soot filters based on the Clean Air Act for a decade (2017-2026) in Tehran.

Materials and methods

Study area

The capital of Iran, Tehran (Fig. 1), is situated in the country's northern region at coordinates 35.6892° N and 51.3890° E. with 22 municipal districts, Tehran is considered as one of the fastest-growing cities in the world but also one of the most polluted. The city experiences a Mediterranean rainfall pattern and has a semi-arid, cold climate [14]. The pollution in Tehran stems from various interacting factors, including population, geography, meteorological conditions, and industrial activities [7]. This city has 35 Air Quality Monitoring Stations (AQMSs) [15]. These stations report PM_{10}, $PM_{2.5}$, NO_2, O_3, SO_2, and CO levels hourly [14].

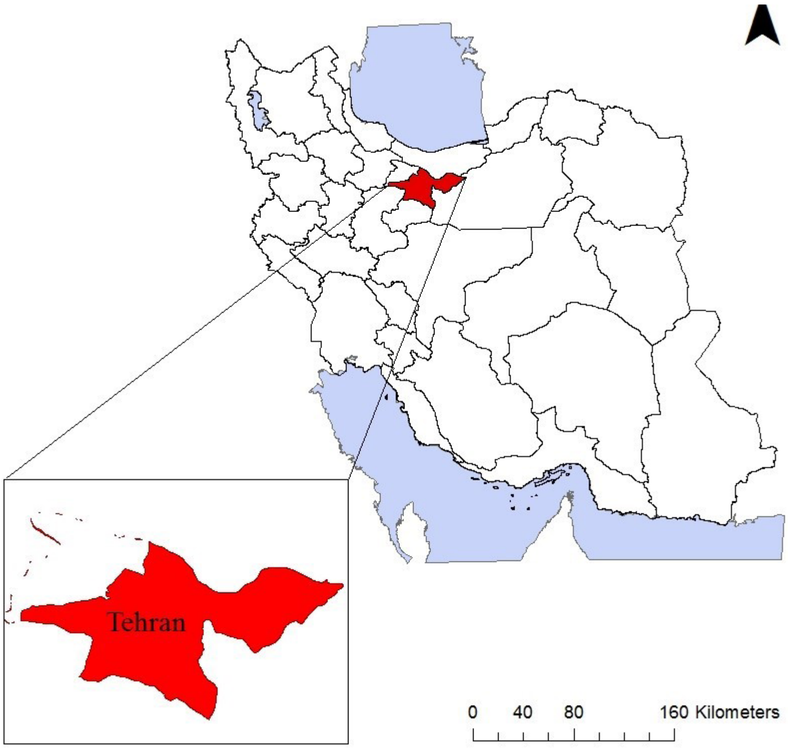

Fig. 1. Location of Tehran city in Iran

Table 1. Demographic Information of Tehran

	Demographic Information/Person									
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Children under 5 years old	991000	997000	1000000	864000	992000	973000	953000	931000	908000	886000
Adults over 25 years old	8976000	9132000	9247000	9409000	9539000	9663000	9785000	9904000	10018000	10131000
Adults over 30 years old	7706000	7934000	8148000	8348000	8532000	8696000	8845000	8981000	9106000	9225000
sum	13461000	13636000	13807000	13973000	14134000	14289000	14437000	14579000	14714000	14843000

Demographic information

Demographic data for the study was obtained from the Iran Statistics Center website [16]. The data includes population information for Tehran province from 2017 to 2026, categorized by age, sex, and residential areas such as urban, rural, and non-residential. Excel was used to categorize the population of adults over 25 and 30 years old as well as children under five years old (Table 1).

Meteorological data

Meteorological data of Mehrabad station for entry into AERMOD model were obtained from the website of the Meteorological Organization with official permission. The station's coordinates were 51.3890 longitude, 35.6892 latitude, and it was situated at an altitude of 1191 meters above sea level. Surface properties like reflection (whiteness coefficient), surface roughness length, and Bowen ratio, along with meteorological observations for both hot and cold seasons (wind speed, wind direction, relative humidity, temperature, and precipitation), were used as inputs for AERMET. The receptors were defined as a geographical network covering an area of 70x50 km^2, with a network distance of 5000 grids in both X and Y directions.

Scenarios

Three scenarios were extracted from Iran's Clean Air Law with the aim of reducing outdoor air pollution caused by vehicles. Scenario 1 involves decommissioning end-of-life cars in Tehran between 2017 and 2026, as outlined in the Iran Comprehensive National Air Pollution Reduction Program. Scenario 2 focuses on decommissioning End-of-Life Motorcycles (ELMCs) in Tehran during the same period. Scenario 3 entails equipping buses in Tehran with soot filters between 2017 and 2026 in accordance with the Iran Comprehensive National Air Pollution Reduction Program.

$PM_{2.5}$ emission data gathering and processing

To determine the emission weight of $PM_{2.5}$ per ton per year for scenarios 2 and 3, data were extracted from the Comprehensive National Air Pollution Reduction Program [17], as presented in Table 2. However, for scenario 1, we calculated the weight of emitted particles using Eq. 1 due to insufficient information in the comprehensive plan.

$$EW = N \times M \times E \tag{1}$$

This equation calculates the weight of $PM_{2.5}$ emissions from end-of-life cars in 2017. 'EW' is the emission weight indicator, while 'N' represents the total number of end-of-life cars in 2017, 'M' is the average passenger car mileage per day, and 'E' denotes the emissions per car per kilometer/mile based on the emission coefficient of the International Vehicle Emissions (IVE) model.

We calculated the emission weights for the base year of 2017 and used the reduction percentages mentioned in the comprehensive program to calculate the emission weights for the upcoming years for scenarios 2 and 3. It should be noted that we considered the reduction percentage for end-of-life cars (scenario 1) similar to ELMCs. After calculating the emission weights for each of the three scenarios, we added them together. Then, the resulting numbers, background concentration numbers, and other relevant data were entered into the AERMOD software to convert emission weight units to emission concentrations. After obtaining the results, using a simple equation, the sum of $PM_{2.5}$ concentrations were divided into independent concentration numbers emitted by ELMCs, end-of-life cars, and buses without soot filters. Finally, the data were entered into the AirQ+ and for each parameter, we create a new impact evaluation. The primary reason for adopting AERMOD was to convert emission weight units to emission concentrations. The accessible data units were Ton/Year, and it was essential to convert them to $\mu g/m^3$ in order to enter the data into the AIRQ + software. Moreover, It should also be noted that the background concentration value up to 2020 was determined based on the average background concentration of measuring stations in the same year, which showed a decreasing trend. But for the years 2020 to 2026, the average background concentration of previous years was used.

Table 2. Comprehensive national air pollution reduction program, presented by the environmental protection agency and the consortium of top universities in Iran

Approach	Target fleet number				Release type	Emission of pollutants (Ton / year)	Emission of pollutants after the implementation of the solution (Ton/year)	Reduction Percentage (Ton/year)
	Short term	Mid term	Long time	Total				
Replacing worn-out trucks with Euro 4 trucks with soot filters	690	1,700	4,495	6,885	PM	4,537	4,438	2%
Convert non-end-of-life carburetor motorcycles into injectors	14,600	36,500	94,900	146,000	PM	4,537	2937	33.4%

Table 3. Incidence rates

	Incidence rate (per 100 000 population at risk)
Mortality due to COPD for adults age 30+ years	11/89
Mortality due to lung cancer for adults age 30+ years	14/33
Mortality due to all causes for adults age 30+ years	688/15
Mortality due to IHD for adults age 25+ years	116/95
Mortality due to stroke for adults age 25+ years	56/67
Mortality due to ALRI in children age 0-5 years	7/37

Economic burden and health risk assessment

The concentration of $PM_{2.5}$ for the first and second scenarios and the sum of three scenarios, along with demographic information and the baseline incidence rate-which was extracted from previous studies and was considered the same for all years (Table 3) [18]-for deaths related to air pollution were entered into the AIRQ+. For the 3rd scenario, the AERMOD output result was less than the WHO AIR Quality Guideline (AQG) and AIRQ+ software limits, so it was not evaluated separately.

The economic effects of deaths attributed to air pollution were determined using the Value of Statistical Life (VSL) method. In order to determine the value of statistical life in Tehran, the value of the statistical life of countries that are members of the Economic Cooperation and Development (OECD) was used. In this way, according to the recommendation of the World Bank, the average value of the statistical life in OECD countries (4.83 and 5.35 million dollars) was taken. Afterward, this value was adjusted to suit Iran's conditions using the Eq. 2.

$$VSL_{Iran} = VSL_{OECD} \times (GDP_{Iran} / GDP_{OECD})^{e} \quad (2)$$

In this equation, GDP_{Iran} and GDP_{OECD} are indicators of Gross Domestic Product (GDP) per capita in Iran and OECD countries, respectively. In addition, the symbol 'e' represents a conversion factor that adjusts income in different countries, with a recommended value by the World Bank of 1 to 1.4 for low- and middle-income countries. According to the World Bank, the assumed GDP for Iran is 5469.8 dollars, and for OECD countries, the value is 42469. Assuming the value of 'e' to be 1.2, the statistical life value of an Iranian individual was calculated using the mentioned formula. This value was then incorporated into Eq. 3 to determine the extent of damage and death caused by suspended particles in Iran between 2017 and 2026 [19].

$$\text{Value of Life Lost} = VSL_{Iran} \times N \quad (3)$$

In this equation, 'N' indicates the number of deaths attributed to exposure to $PM_{2.5}$ in Tehran [19].

Results and discussion

In this study, we aim to assess the impact of reducing the amount of $PM_{2.5}$ on the death rate and economic expenses related to this harmful pollutant. Tables 4 and 5 provide information on the weight and concentration of $PM_{2.5}$ particles emitted from vehicles in the three considered scenarios, and it can be seen that the weight and concentration of $PM_{2.5}$ in each scenario have a downward trend from 2017 to 2026. According to Table 5, the average annual concentration of $PM_{2.5}$ released from end-of-life cars and motorcycles exceeds the recommended limit of WHO's AQG ($PM_{2.5}$=5 $\mu g/m^3$). However, for buses without soot filters, the concentration is below the standard. This difference is due to the small number of buses without soot filters compared to the number of vehicles in the other scenarios.

Table 4. Emission weight of $PM_{2.5}$ particles emitted from vehicles for the study period (Ton/Year)

	$PM_{2.5}$ emissions (Ton/year)									
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
End-of-life cars	4647[a]	4636	4625	4614	4603	4592	4581	4570	4559	4548
ELMCs	4537	4526	4515	4505	4494	4483	4472	4461	4450	4440
Buses without soot filters	987	947	908	869	829	790	751	711	672	633
Sum	10171	10109	10048	9987	9926	9865	9804	9743	9682	9620

ELMCs: end-of-life motorcycles.
[a] Input data to AERMOD

Table 5. The estimated concentration of $PM_{2.5}$ particles emitted from vehicles for the study period (μg/m^3)

	$PM_{2.5}$ concentrations (μg/m^3)									
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
End-of-life cars	15.68[a]	14.23	14.23	14.62	14.83	14.82	14.80	14.79	14.78	14.77
ELMCs	15.31	13.89	13.89	14.27	14.48	14.64	14.45	14.44	14.43	14.42
Buses without soot filters	3.33	2.90	2.79	2.75	2.67	2.56	2.44	2.31	2.21	2.10
Sum	34.34	32.29	32.15	32.08	31.98	31.85	31.71	31.57	31.44	31.30

ELMCs: end-of-life motorcycles.
[a] output data of AERMOD

Mortality attributed to $PM_{2.5}$

Based on Fig. 2, all diagrams generated by AIRQ+ display a similar pattern. The death rate decreased as the concentration of $PM_{2.5}$ decreased between 2017 and 2021. In addition, from 2022 to 2026, assuming the background concentration remains constant, a decreasing trend is still observed. In fact, it can be claimed that if the background concentration of the city remains constant or decreases in comprehensive and detailed plans, along with the reduction of $PM_{2.5}$ emitted from ELVs, a decrease in deaths due to air pollution will be observed.

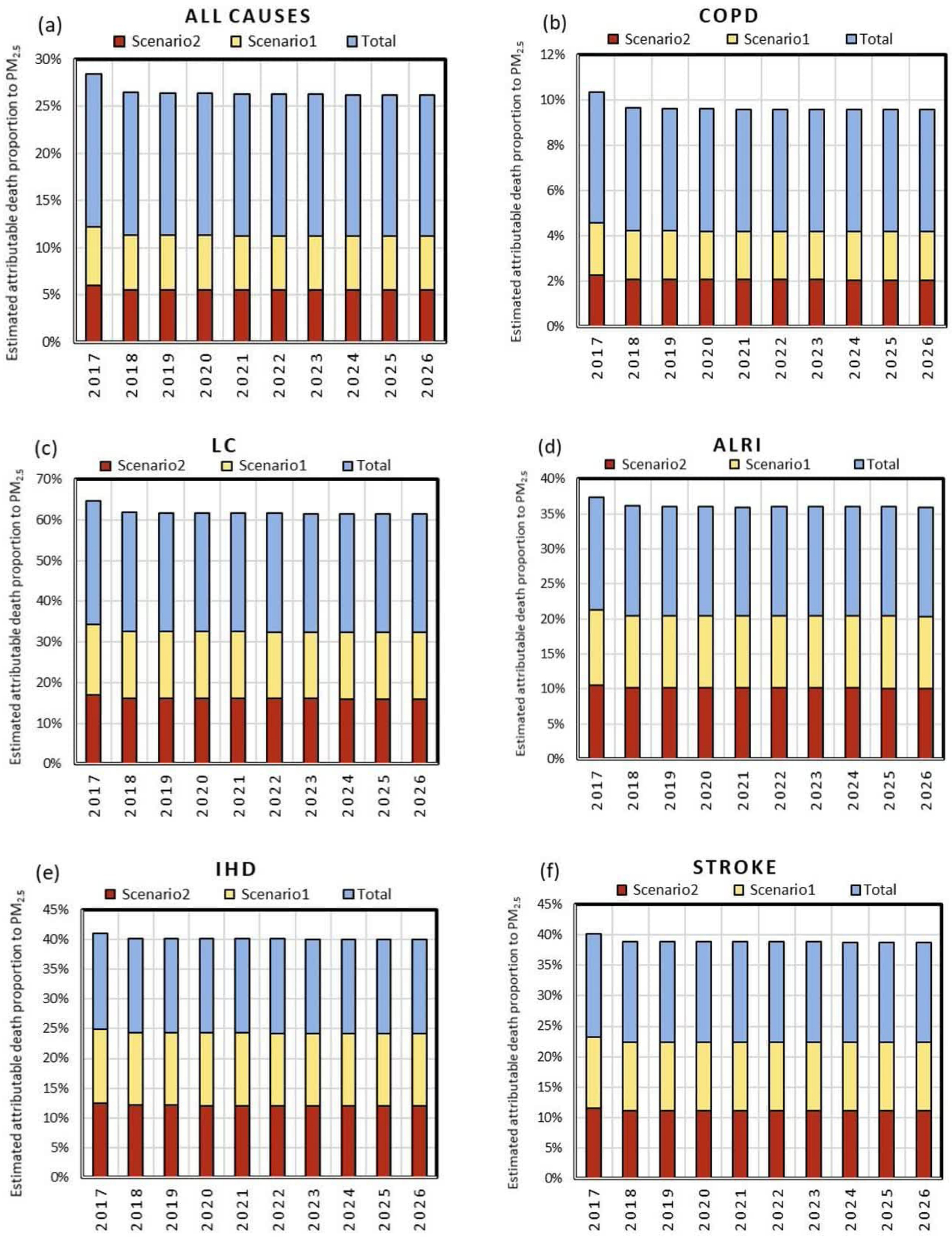

Fig. 2. Estimated attributable death proportion to $PM_{2.5}$ particles for the first and second scenarios and the total of three scenarios during ten years in Tehran. Scenario 1: decommissioning end-of-life cars; Scenario 2: decommissioning end-of-life motorcycles; Total: the sum of scenarios 1, 2, and 3 (equipping buses with soot filters)

The findings presented in Fig. 2 indicate that during a ten-year period, scenario 1 resulted in a 6.75% decrease in the estimated proportion of deaths attributed to all causes, a 2.54% decrease in deaths caused by COPD, an 18.40% decrease in deaths from LC, an 11.16% decrease in deaths caused by ALRI, a 12.82% decrease in deaths caused by IHD, and a 12.12% decrease in deaths caused by stroke. Similarly, scenario 2 resulted in a reduction of deaths caused by all the mentioned factors by 6.53%, 2.46%, 18.40%, 11%, 12.69%, and 11.96%, respectively. Over ten years, implementing three scenarios of decommissioning end-of-life cars and motorcycles and equipping buses with soot filters reduced deaths attributed to air pollution. The scenarios reduced deaths due to all causes, COPD, LC, ALRI, IHD, and stroke, by 17.41%, 6.16%, 31.51%, 16.58%, 16.5%, and 17.38%, respectively. This approach significantly lowered the estimated proportion of deaths attributable to $PM_{2.5}$ particles compared to the previous two scenarios. These downward trends are similar to a study by many researchers [20]. According to their reports, the adult mortality rates caused by $PM_{2.5}$ decreased between 2008 and 2014. This decrease was attributed to the reduction of air pollutants in Camp de Tarragona County in Spain in order to comply with the standards of the World Health Organization.

Air pollution is one of the problems that endangers human life. Several studies in Tehran indicate the negative effects of air pollution on human health. In 2017, researchers estimated that in Tehran, $PM_{2.5}$ was responsible for 7146 deaths in adults (age≥25) and ischemic heart disease were the primary causes of them [21]. Moreover, other vresearchers found that between March 2013 and March 2016, 5073 natural deaths, 158 death due to COPD, and 142 deaths due to lung cancer in people over 30 years old in Tehran were linked to long-term exposure to $PM_{2.5}$ [22]. All three health endpoints showed that the mortality attributed to $PM_{2.5}$ decreased yearly from 2013 to 2016 and the decrease in deaths was linked to a corresponding reduction in the concentration of $PM_{2.5}$. Furthermore, a study showed an association between hospital admissions for AURI and ALRI and exposure to outdoor air pollutants which includes PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, and CO in Tehran [23].

After clarifying the negative effects of air pollutants on health, researchers investigated the impacts of reducing air pollutants on both mortality rates and economic costs [24-26]. However, very few studies have been conducted on the effectiveness of laws aimed to reducing air pollution and its consequences. A similar study evaluated the effectiveness of the National Clean Air Program in terms of the health consequences of $PM_{2.5}$ and NO_2 concentrations in Poland. It claimed that replacing inefficient stoves and boilers in houses as part of the mitigation approach significantly reduced particulate matter and reduced premature death by about 3000 cases [27]. Additionally, researchers in a study evaluated the health burden and economic impacts of $PM_{2.5}$ in China from 2010 to 2050 using a variety of Representative Concentration Pathway (RCP) scenarios [28]. It is found that the predicted death rate from long-term exposure to $PM_{2.5}$ pollution in China will drop by 2050 under RCP2.6, RCP4.5, and RCP8.5. In addition, the rise in population will, unfortunately, lead to a higher number of deaths, offsetting some of the positive effects of reduced air pollution between 2010 and 2050. According to a study conducted by many researchers [29] in Italy, the impact of air pollution on human health has generally decreased during 2010-2019, as air pollutants and $PM_{2.5}$ levels have decreased. However, it is important to note that during this period, air pollution levels were still higher than the standard level, which is consistent with the conditions of this research. In addition, similar results have been obtained from studies by researchers [18, 20] studies. In a study, it was conducted a study on $PM_{2.5}$ concentrations in ten cities in Iran from 2013 to 2016. The study revealed that in all cities except Ahvaz and Khoram Abad, the concentrations of $PM_{2.5}$ in the third year were significantly lower than the first year. In Ahvaz and Khoram Abad, the concentration of $PM_{2.5}$ in the third year was much lower than the second year, and generally expect for Ahvaz, Khoram Abad, and Ilam, the health effects reduced in the third year compared to the first year. The researchers shared that cities in the west and south of the country experience high mortality rates due to severe dust storms and air pollution. Tehran, however, has fewer deaths but is mainly affected by $PM_{2.5}$ emissions from industries and traffic.

Economic benefits of reduced premature mortality

In addition to health effects, air pollution imposes economic costs on societies. Studies have demonstrated that the expenses associated with treatment, decreased labor productivity, and the prevalence of diseases caused by air pollution, as well as the annual mortality rate may impose a significant economic cost on communities [30]. According to a study in Tehran, cardiovascular diseases, diabetes, lung cancer, respectively, which are caused by air pollution have the most significant financial burdens to the healthcare system [31]. According to the statistical data, air pollution in Tehran caused economic burdens amounting to $ 2.6 billion through mortality and morbidity in 2016 [32]. In addition, according to an estimation by many researchers, the annual economic benefits of decreasing the concentration of air pollution in Tehran in 2017 to 10 and 15 $\mu g/m^3$ (WHO recommended standard and the United States federal annual average standard), would be $1689 and $950 million, respectively [33]. However, our estimates of the economic benefits associated with reducing $PM_{2.5}$ demonstrate an upward trend in deaths due to all causes, COPD, LC, ALRI, IHD, and stroke for all scenarios. The increase in population in this period appears to be a significant contributing factor to this trend.

Based on Fig. 3, the economic cost due to the reduction of deaths from all causes in the scenario of decommissioning end-of-life cars over ten years increased to 126.34 million dollars. In addition, the economic cost of reducing deaths due to COPD, LC, ALRI, IHD, and stroke increased by 0.78, 9.8, 0.39, 51.40, and 20.02 million dollars, respectively. As well, in the scenario of decommissioning ELMCs over ten years, the economic cost of reducing deaths due to all causes increased by 170.28 million dollars, and similar to the previous scenario, the economic cost of reducing deaths due to COPD, LC, ALRI, IHD, and stroke increased by 0.78, 9.8,0.39, 51.40, and 20.02 million dollars, respectively. Decommissioning end-of-life cars and motorcycles and equipping buses with soot filters over the ten-year led to an increase in economic costs amounting to 357.44 million dollars due to the reduction of deaths from all causes. Moreover, the economic cost increased by 2.35, 19.61, 0.78, 70.62, and 32.56 million dollars due to the reduction of mortality due to COPD, LC, ALRI, IHD, and stroke, respectively. The cost increase in this scenario is higher than the previous two scenarios. The upward trend of these results is similar to some part of a study [28]. According to their study, during 2020–2030, Medical Expenses (ME) under the RCP6.0 scenario kept rising, whereas the ME under the other three scenarios fell [34]. It can be seen that the results of the RCP6.0 scenario are consistent with the results of this study. However, there were also conflicting results between the mentioned studies and our research. One of the reasons for this is the fact that the mentioned studies were conducted on a population that remained constant for a single year or had a small changes over a certain period of time. This can create an incompatibility between the results of these studies and our research.

In 2018, researchers published a study that evaluated the health effects of two hypothetical policy scenarios [35]. The first scenario was to reduce $PM_{2.5}$ to the amount recommended by the European Union (25 $\mu g/m^3$), whereas the second scenario was to reduce particles to the level suggested by WHO (10 $\mu g/m^3$). According to the findings, a hypothetical implementation of the EU rules might have averted 45% of premature deaths and about 20% of hospital admissions for cardiovascular and respiratory disorders, resulting in social cost savings ranging from 251 to 697 M€. A potential further reduction of PM levels to the WHO's AQG might have saved 77% of premature deaths, nearly 50% of hospital admissions for both cardiac and respiratory disorders, and 407-1081 M€ in social costs.

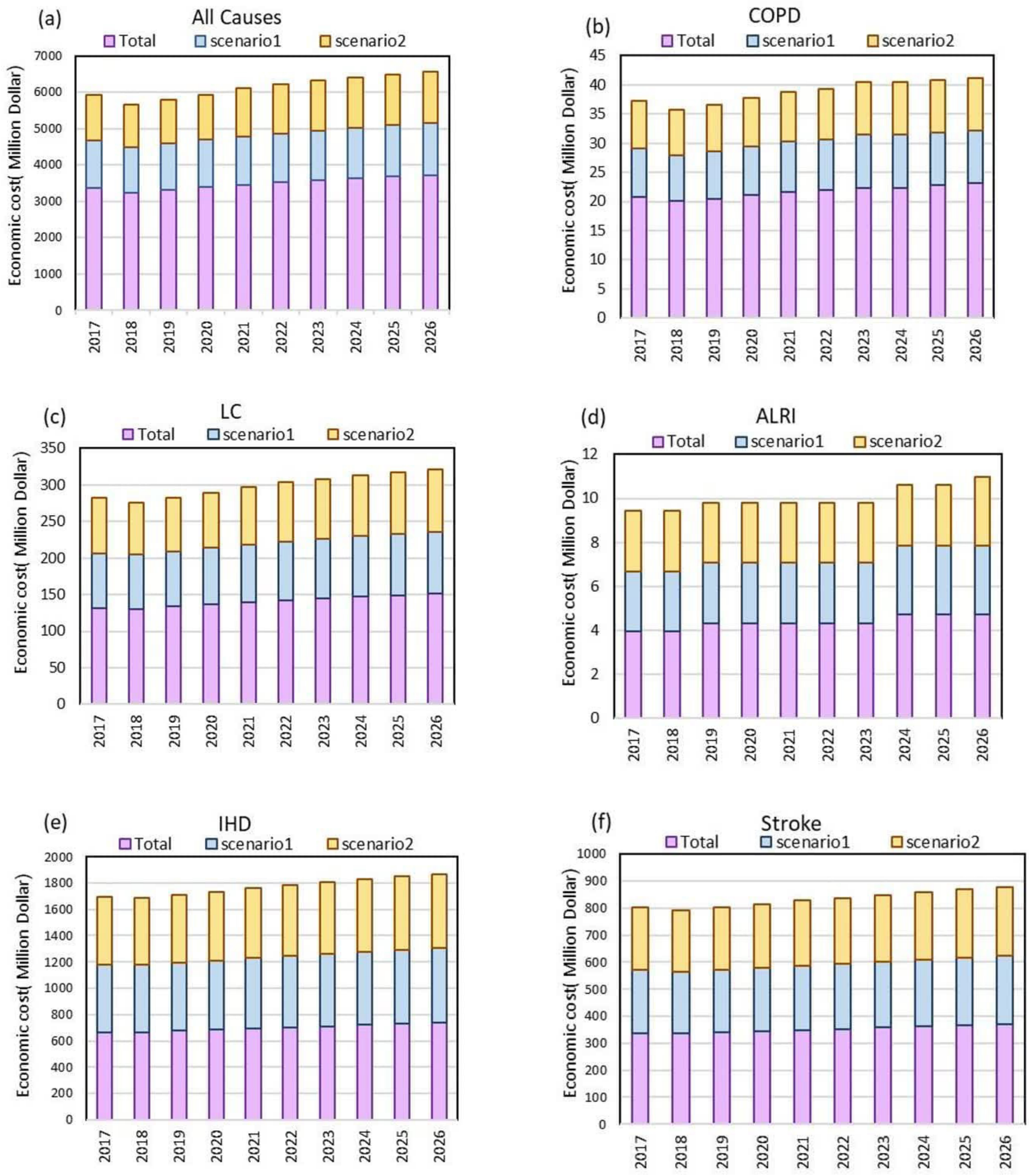

Fig. 3. The estimated economic cost of mortality (in millions of US dollars per year) due to $PM_{2.5}$ for the first and second scenarios and the total of three scenarios during ten years in Tehran. Scenario 1: decommissioning end-of-life cars; Scenario 2: decommissioning end-of-life motorcycles; Total: the sum of scenarios 1 and 2, and 3 (equipping buses with soot filters).

Extensive research has been done to determine the health effects and economic costs of air pollution in Iran [6, 14]. However, there is a noticeable absence of research on the health and economic effects of broad-scale programs related to air pollution. This study has provided valuable insights and is the first study in Iran to evaluate the health and economic effects of reducing $PM_{2.5}$ particles through the partial implementation of the Iran's Clean Air Act. However, the main limitation of this study was the lack of sufficient information about the concentration of $PM_{2.5}$ emitted from ELVs in Tehran. Our data was based on the Comprehensive National Air Pollution Reduction Program and AERMOD's output, which did not allow us to make more accurate calculations. So future research with more accurate numbers might provide more precise proof to verify this claim. Moreover, we just evaluated the effect of decommissioning ELVs and equipping buses with soot filters on the reduction of deaths related to air pollution, and the effects of factors such as improving the fuel quality and applying strict rules for polluting industries, etc were not investigated. It is obvious that comprehensive studies can provide more accurate results.

Conclusion

As cities continue to grow and industries expand, especially in developing countries, we need to develop and evaluate programs to reduce the pollution caused by these phenomena. Air pollution is one of the issues of urbanization and industrialization that can potentially affect human life [36]. Globally, there have been numerous programs designed and carried out to combat $PM_{2.5}$ pollution, and it is necessary to evaluate their effectiveness. This study provides evidence for the effect of Clean Air Act in Tehran, on reducing the estimated attributable death proportion to $PM_{2.5}$ and its costs. The decommissioning of end-of-life cars and motorcycles and equipping buses with soot filters mentioned in the Clean Air Act have a positive effect on reducing the estimated attributable death proportion in Tehran over ten years. However, due to population growth, the economic cost increases, which requires more detailed planning. Therefore, more active and precise actions to reduce air pollution emission are required to ensure that premature deaths and the associated economic costs are effectively prevented.

Financial supports

This work was supported by Shahid Beheshti University of Medical Sciences, Tehran, Iran. (Grant Numbers: 26922 – 26948 - 31317).

Competing interests

The authors declare no competing interests.

Authors' contributions

Mozhgan Panji: data curation, formal analysis, investigation, software, writing original draft, project administration. Abbass Shahsavani: conceptualization, methodology, funding acquisition, supervision. Yousef Rashidi: methodology, conceptualization. Seyed Saeid Hashemi Nazari: methodology and formal analysis. Anoushiravan Mohseni Bandpey: review and editing. Majid Kermani: review and editing. Zahra Namvar: review and editing.

Acknowledgements

We wish to thank Shahid Beheshti University of Medical Sciences. We thank the Center for Environmental and Occupational Health of the Ministry of Health and Medical Education, the Environmental Protection Organization, and the Meteorological Organization of Iran.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors.

References

1. Faridi S, Shamsipour M, Krzyzanowski M, Künzli N, Amini H, Azimi F, et al. Long-term

trends and health impact of $PM_{2.5}$ and O_3 in Tehran, Iran, 2006–2015. Environment international. 2018;114:37-49.

2. Adam M, Schikowski T, Carsin AE, Cai Y, Jacquemin B, Sanchez M, et al. Adult lung function and long-term air pollution exposure. ESCAPE: a multicentre cohort study and meta-analysis. European respiratory journal. 2015;45(1):38-50.

3. Pozzer A, Anenberg S, Dey S, Haines A, Lelieveld J, Chowdhury S. Mortality attributable to ambient air pollution: A review of global estimates. GeoHealth. 2023;7(1):e2022GH000711.

4. Ansari M, Ehrampoush MH. Meteorological correlates and AirQ+ health risk assessment of ambient fine particulate matter in Tehran, Iran. Environmental research. 2019;170:141-50.

5. Naghan DJ, Neisi A, Goudarzi G, Dastoorpoor M, Fadaei A, Angali KA. Evaluation of ozone, $PM_{2.5}$ and NO_2 concentrations and estimation of attributed health effects based on AirQ+ on residents of Ahvaz, Iran (2012-2018). Journal of Air Pollution and Health. 2021; 6(4): 243-256.

6. Hadei M, Hopke PK, Shahsavani A, Jahanmehr N, Rahmatinia M, Farhadi M, et al. Mortality and morbidity economic burden due to $PM_{2.5}$ and ozone: An AirQ+ modelling in Iran. Journal of Air Pollution and Health. 2020 May 26;5(1):1-0.

7. Halek F, Kavouci A, Montehaie H. Role of motor-vehicles and trend of air borne particulate in the Great Tehran area, Iran. International journal of environmental health research. 2004;14(4):307-13.

8. Mohammadiha A, Malakooti H, Esfahanian V. Development of reduction scenarios for criteria air pollutants emission in Tehran Traffic Sector, Iran. Science of the Total Environment. 2018;622:17-28.

9. Shahbazi H, Reyhanian M, Hosseini V, Afshin H. The relative contributions of mobile sources to air pollutant emissions in Tehran, Iran: an emission inventory approach. Emission control science and technology. 2016;2:44-56.

10. Iran ICo. Clean Air Law [In Persian]: Islamic Council Research Center; 2017 [Available from: https://rc.majlis.ir/fa/law/show/1030618.

11. Henneman LR, Liu C, Mulholland JA, Russell AG. Evaluating the effectiveness of air quality regulations: A review of accountability studies and frameworks. Journal of the Air & Waste Management Association. 2017;67(2):144-72.

12. Oliveri Conti G, Heibati B, Kloog I, Fiore M, Ferrante M. A review of AirQ Models and their applications for forecasting the air pollution health outcomes. Environmental Science and Pollution Research. 2017;24:6426-45.

13. Macêdo MFM, Ramos ALD. Vehicle atmospheric pollution evaluation using AERMOD model at avenue in a Brazilian capital city. Air quality, atmosphere & health. 2020;13:309-20.

14. Yunesian M, Rostami R, Zarei A, Fazlzadeh M, Janjani H. Exposure to high levels of $PM_{2.5}$ and PM_{10} in the metropolis of Tehran and the associated health risks during 2016–2017. Microchemical Journal. 2019;150:104174.

15. Company AQC. Archive of daily reports Tehran Air Quality Control Company2023 [Available from: http://airnow.tehran.ir/home/DaiyAQIArchive.aspx.

16. Iran´s Statistics Center 2022 [Available from: https://www.amar.org.ir/.

17. Mahotchi-saeed K, Esfahanian V, Ahmadikia H, Ohadi-Hamedani A, Hojat Y, Khazini L, et al. The management report of preparing the air pollutant release list, including man-made sources, and compiling and evaluating the main scenarios for reducing air pollution in Iran's metropolises.2021.

18. Hopke PK, Nazari SSH, Hadei M, Yarahmadi M, Kermani M, Yarahmadi E, et al. Spatial and temporal trends of short-term health impacts of PM2. 5 in Iranian cities; a modelling approach (2013-2016). Aerosol and air quality research. 2018;18(2):497-504.

19. Shahsavani A, Jandaghi J, Mohseni bandpey A, Farhadi M, Kermani M, Yarahmadi M, et al. Report on the quantification of health and economic effects attributed to PM in 27 cities of the country in 1400, Tehran: Ministry of Health and Medical Education 2022.

20. Rovira J, Domingo JL, Schuhmacher M. Air quality, health impacts and burden of disease due to air pollution (PM_{10}, $PM_{2.5}$, NO_2 and O_3): Application of AirQ+ model to the Camp de Tarragona County (Catalonia, Spain). Science of The Total Environment. 2020;703:135538.

21. Bayat R, Ashrafi K, Shafiepour Motlagh M, Hassanvand MS, Daroudi R, Fink G, et al. Health impact and related cost of ambient air pollution in Tehran. Environmental Research. 2019;176:108547.

22. Yarahmadi M, Hadei M, Nazari SSH, Conti GO, Alipour MR, Ferrante M, et al. Mortality assessment attributed to long-term exposure to fine particles in ambient air of the megacity of Tehran, Iran. Environmental Science and Pollution Research. 2018;25(14):14254-62.

23. Namvar Z, Hadei M, Hashemi SS, Shahhosseini E, Hopke PK, Rahmatinia M, et al. Air pollution and hospital admissions and deaths due to respiratory infections in megacity of Tehran: A time series analysis. Journal of Air Pollution and Health. 2021.

24. Aldegunde JAÁ, Bolaños EQ, Fernández-Sánchez A, Saba M, Caraballo L. Environmental and Health Benefits Assessment of Reducing PM2. 5 Concentrations in Urban Areas in Developing Countries: Case Study Cartagena de Indias. Environments. 2023;10(3):42.

25. Pisoni E, Thunis P, De Meij A, Wilson J, Bessagnet B, Crippa M, et al. Modelling the air quality benefits of EU climate mitigation policies using two different PM2. 5-related health impact methodologies. Environment International. 2023;172:107760.

26. Xie Y, Zhong H, Weng Z, Guo X, Kim SE, Wu S. PM2. 5 concentration declining saves health expenditure in China. Frontiers of Environmental Science & Engineering. 2023;17(7):90.

27. Jagiełło P, Struzewska J, Jeleniewicz G, Kamiński JW. Evaluation of the Effectiveness of the National Clean Air Programme in Terms of Health Impacts from Exposure to $PM_{2.5}$ and NO_2 Concentrations in Poland. International Journal of Environmental Research and Public Health. 2022;20(1):530.

28. Wang Y, Hu J, Zhu J, Li J, Qin M, Liao H, et al. Health Burden and economic impacts attributed to PM2. 5 and O_3 in China from 2010 to 2050 under different representative concentration pathway scenarios. Resources, Conservation and Recycling. 2021;173:105731.

29. Toscano D, Murena F. The historical trend of air pollution and its impact on human health in Campania region (Italy). Atmosphere. 2021;12(5):553.

30. Kochi I, Loomis J, Champ P, Donovan G, editors. Health and economic impact of wildfires: literature review and impact assessment. Proceedings of the Third International Symposium on Fire Economics, Planning, and Policy: Common Approaches and Problems; 2010: DIANE Publishing.

31. Khoshakhlagh AH, Mohammadzadeh M, Morais S. Air quality in Tehran, Iran: Spatio-temporal characteristics, human health effects, economic costs and recommendations for good practice. Atmospheric Environment: X. 2023;19:100222.

32. Heger M, Sarraf M, Heger MP. Air pollution in Tehran: health costs, sources, and policies. 2018.

33. Bayat R, Ashrafi K, Motlagh MS, Hassanvand MS, Daroudi R, Fink G, et al. Health impact and related cost of ambient air pollution in Tehran. Environmental research. 2019;176:108547.

34. Wang Y, Hu J, Zhu J, Li J, Qin M, Liao H, et al. Health Burden and economic impacts attributed to $PM_{2.5}$ and O_3 in china from 2010 to 2050 under different representative concentration pathway scenarios. Resources, Conservation and Recycling. 2021;173:105731.

35. Martinez GS, Spadaro JV, Chapizanis D, Kendrovski V, Kochubovski M, Mudu P. Health impacts and economic costs of air pollution in the metropolitan area of Skopje. International journal of environmental research and public health. 2018;15(4):626.

36. Tabibzadeh SA-S, Hosseini SA, Mohammadi P, Etminan A, Norouzi H. Quantification of mortality associated with particulate matter using air Q model in ambient air in Shiraz, Iran. Polish Journal of Environmental Studies. 2022;31(1):551-9.