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Review Paper

Catalyzing healthier air: the impact of escalating fossil fuel prices on air quality and public health and the need for transition to clean fuels

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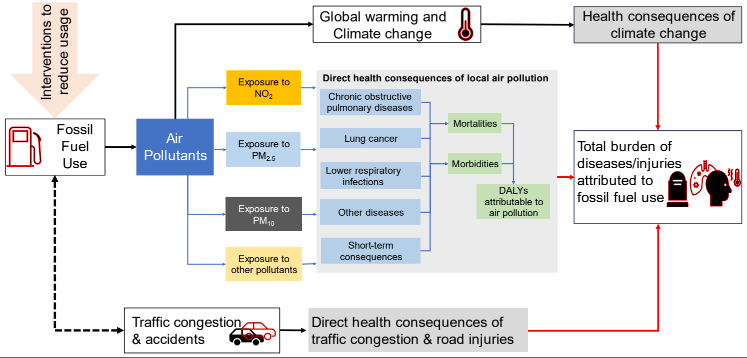
HIGHLIGHTS

- ➢ Fossil fuel pricing interventions are effective in reducing their short- and long-term consumption.
- ➢ Increasing consumer price of fossil fuel reduces air pollutants such as NOx and particulate matter.
- ➢ Pricing interventions impact population health by reducing air pollution mortalities and morbidities.
- ➢ Pro-rich policies of subsidizing fossil fuels should be replaced by policies that support population health, environment, and equity.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, we reviewed previous information regarding the effect of fossil fuel pricing intervention on the consumption of fossil fuels, air quality, and population health. In a rapid review, we searched and reviewed reports about the effect of fossil fuel pricing interventions on each or some of the following outcomes: fossil fuel consumption, concentrations of air pollutants, and mortalities or morbidities attributable to exposure to air pollutants. As part of our investigation, we also present the findings of an unpublished, original study that specifically estimated the effects of an elevated gasoline price in Iran's ten most populous cities. Pricing interventions were effective in reducing the consumption of fossil fuels, both in developing and developed countries. Price elasticity for transport gasoline was reported to be -0.227 and -0.715 for short- and long-term, respectively. Reductions in concentrations of air pollutants, especially NO_x and particulate matter, were reported in several studies. This review study demonstrates the effects of escalating fossil fuel prices on reducing consumption, air pollution, and mortalities and morbidities attributable to air pollution. Considering the external costs of fossil fuels through environmental, climate, traffic congestions and accidents, and population health, the real costs of fossil fuels are much higher than their retail price. Pro-rich policies of subsidizing fossil fuels should be replaced by alternative policies that support clean public transport, which is suitable for population health, environment, and equity.

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Contents

1. Introduction

According to the World Health Organization (WHO), around 6.7 million annual deaths are attributable to air pollution globally. Air pollution is the second most important risk factor for non-communicable diseases (WHO, 2024). A large body of literature confirms the link between air pollution and a broad range of respiratory and cardiovascular diseases, cancers, and other chronic diseases (EPA, 2020). In the long term, air pollution is a major contributor to climate change, threatening all achievements of public health in the previous centuries (Romanello et al., 2022). On the other hand, fossil fuels have volatile and unpredictable markets, are interconnected with supply chains, and are commonly played as a geopolitical card. Many countries are still paying different sorts of subsidies to make fossil fuels available to the public (He et al., 2017; Coady et al., 2019). For instance, most of the member states of the Organization of Petroleum Exporting Countries (OPEC) are among the top twenty countries with the lowest gasoline and diesel prices worldwide (Davis, 2017). In addition to the direct subsidies to reduce the costs of fossil fuels, there are implicit subsidies due to inefficient pricing that give rise to social costs (Kotchen, 2021). Davis (2017) compared the subsidized price of fuels with its private costs and social costs; a subsidized fuel price, which is less than its private costs, leads to an inefficient excess consumption of fuels that its private benefits are less than its costs. This "deadweight loss" of subsidized fuels has been estimated to be 26 billion annually and is separate from the external costs of using fossil fuels. External costs incurred by the population due to local air pollution, traffic congestion and accidents, climate change, and health impacts of using fossil fuels are estimated to be 44 billion annually (Davis, 2017).

The costs of fossil fuel used for transportation are different from its retail price; its comprehensive costs include supply cost, environmental costs (local air pollution and global warming), congestion and traffic costs, as well as road maintenance costs and traffic accidents costs (Coady et al., 2019). Subsidies and taxation also affect the price for consumers considerably and are important determinants of usage and equity. The interventions that directly affect consumer prices for transportation have a wide range, such as air pollution fees, congestion charging, fuel taxes or price increases, mileage-based user fees, parking charges, road pricing, pricing incentives, and vehicle ownership taxes (Khreis et al., 2023). In this report, we review the evidence on the effects of different fossil fuel pricing interventions to increase consumer prices on their use, air quality, and eventually on the population's health. Also, several studies have reported significant reductions in mortalities and morbidities attributed to air pollution; most of the decrease in mortality was related to a reduction in exposure to NO_x. We also present the results of a health impact assessment to investigate the effect of increasing the price of gasoline by 50, 80, and 200% on PM_{10}, $PM_{2.5}$, and NO_2 levels and the subsequent health-related outcomes in ten populated cities in Iran using a "Health Risk Assessment, (HIA)" approach as a case study.

2. Methods

We considered a model on the effects of the use of fossil fuels on ambient air pollution and its impact on the incidence and mortality of different diseases in the short- and long-term. In a rapid review study, we searched electronic databases to find reports on the effects of fossil fuel pricing interventions on local air pollution and their impacts on health outcomes, mortality, or disability-adjusted life years (DALY). **Figure 1** demonstrates how we categorize research evidence in the current review paper. We did not review the effects of air pollution on health through greenhouse effects, global warming, and climate change, nor through its impacts on traffic congestion and road injuries.

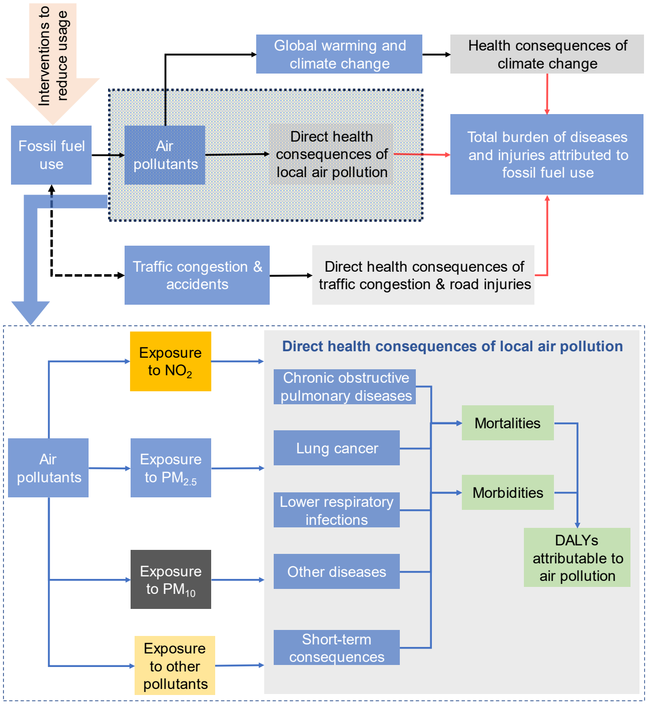

Fig. 1. Model of assessment of the effects of fossil fuel pricing interventions on air pollutants and their impacts on population health (The dashed area in the above image has been zoomed in the lower image).

3. Results and Discussion

We reviewed the results in three different topics: the effects of fossil fuel pricing interventions on its usage, the effects of fossil fuel pricing interventions on air quality, and the impact of fossil fuel pricing interventions on population health.

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3.1. Effects of fossil fuel pricing interventions on its usage

We found several reports that measured or estimated the effects of pricing interventions for fossil fuels on their usage. In Saudi Arabia, a demand function model was used to estimate that adding USD0.41/L to the gasoline price in 2014 (i.e., from a baseline price of 0.16 to USD0.57/L) would decrease its annual total consumption from 24,443 to 11,405 million L (Davis, 2017). Another study estimated an energy consumption's own-price elasticity of -0.63 in 2016 for an average Iranian household (-0.67 for rural and -0.58 for urban households). This means that conditional to no change in other prices and income, a marginal 1% increase in energy carriers' prices would decrease an average Iranian household's consumption of energy by 0.63% (Khatibi et al., 2020). A meta-analysis in 2016 calculated price elasticities of energy demand for short-term and long-term. The random-effect pooled short-term and long-term gasoline price elasticity estimates were -0.227 and -0.715, respectively. Developing and developed countries did not differ in their energy demand price elasticities in the meta-analysis. Also, there was no significant difference between the net energy exporter and net energy importer countries (Labandeira et al., 2017).

3.2. Effects of fossil fuel pricing interventions on air quality

Multiple studies have measured or estimated the effects of fossil fuel pricing interventions on air quality and concentrations of air pollutants. A study examined the effects of higher diesel and petrol prices on traffic-related pollutants in Brisbane (Australia); the researchers reported statistically significant short-term reductions in carbon monoxide and nitrogen oxides by higher diesel prices. However, they did not find any impact on air pollution by increasing petrol (gasoline) prices (Barnett and Knibbs, 2014). Raising diesel taxes in Australia could be justified as a public health measure. As raising taxes is politically unpopular, an alternative political approach would be to remove schemes that put downward pressure on fuel prices, such as industry subsidies and shopping vouchers that give fuel discounts (Barnett and Knibbs, 2014).

A modeling study in Tehran (Iran) estimated different effects of increased fuel price on air quality in the short and long term; the intervention had a greater impact in the long term compared to the short term (Raeissi et al., 2022). A 1% increase in gasoline fuel price in the short term causes 0.020, 0.012, and 0.011% reductions in CO, PM_{10}, and NO_2 concentrations, respectively. In the long term, it leads to 0.027 and 0.016% reductions in concentrations of CO and PM_{10}, respectively (Raeissi et al., 2022). Another study estimated that by increasing fossil fuel prices by 10, 50, 100, 150, and 200% in Iran, a total corresponding reduction in outdoor air pollutants of 2.6, 26.3, 47.6, 62.9, and 74.5 million tons in the post-hike period, respectively, would be expected (Khatibi et al., 2020).

Another study used fixed-effects panel regression methods and estimated that the elimination of the fuel subsidy in Greater Cairo (Egypt) decreases PM_{10} concentrations by nearly 4%. It was also found that an alternative transportation method, the opening of Cairo's Metro Line 3, resulted in about a 3% reduction in air pollution (Heger et al., 2019). Run of the Almost Ideal Demand System (AIDS) and the Quadratic AIDS (QUAIDS) models on the panel data of 306 cities in China from 2002 to 2012 showed that a 30% increase in road transport fuel price could prevent missions of CO, NO_x, and $PM_{2.5}$ by 963,940, 172,000, and 11,330 tons, respectively. The corresponding drop in concentrations is 0.008 mg/m^3, 0.994 $\mu g/m^3$, and 0.160 $\mu g/m^3$, respectively (He et al., 2017). In Mexico, by using the QUAIDS model, it was estimated that the elimination of gasoline subsidy reform would lead to a decrease in household energy consumption by 12.7% and a fall in CO_2 emissions by 5.7% (Labeaga et al., 2016). In an interesting report, Coady et al. (2019) highlighted that efficient fossil fuel pricing in 2015 would have decreased global carbon emissions and deaths attributable to fossil fuel air pollution by 28 and 46%, respectively

The findings of a study on the Panji urban area in China indicated that implementing a carbon emissions tax would positively influence the equilibrium of road network flow and reduce carbon emissions (Yang et al., 2018). A recent analysis examined data from 133 countries over two decades, determining that an increment of USD1 in the average annual retail price of transport fuels is associated with a decrease of 22.2 – 31.1 $\mu g/m^3$ in the annual average concentrations of $PM_{2.5}$ (Mayr and Rentschler, 2023). A study in New Zealand used real data of gasoline and diesel prices, and weekly air pollutants data (PM_{10}, NO_x, $PM_{2.5}$, and CO) from four stations (2001-2013). Although the researchers found reductions in air pollutants, all the reductions were non-significant (Shaw et al., 2018).

3.3. Impact of fossil fuel pricing interventions on population health and well-being

In an evaluation using an integrated modeling chain on the health impacts of a policy to increase car fuel prices in the regions of Flanders and Brussels (Belgium), 1,650 (1,010-2,330) disability-adjusted life years (DALYs) were averted by a 20% increase in price. Although most of the effects were through fewer traffic and road injuries, better air quality was also an important factor. The impact of air quality improvement and increased active travel were mainly on older age, while traffic and road safety mainly affected younger and middle-aged people (Dhondt et al., 2013). A study in the MENAP (the Middle East, North Africa, and Pakistan) region estimated that increasing all energy prices by 50% relative to their baseline levels can decrease air pollution-related premature deaths by 48.7–60.7% (Coady et al., 2015).

A study by Heger et al. (2019) in Cairo revealed that two enacted policies, the removal of the fuel subsidy and the extension of the Metro link, helped in the avoidance of significant mortality and morbidity; this included 364 averted infant deaths due to a decrease in PM_{10} pollution. An analysis of the panel data of 306 cities in China from 2002 to 2012 estimated that a 30% increase in transport fuel (gasoline and diesel) price decreases premature deaths by 16,149 cases; the averted premature deaths were 2,984 cases due to decrease in concentrations of CO, 12,515 for NO_x, and 650 for $PM_{2.5}$ (He et al., 2017).

Box 1 provides a summary of an unpublished study by the authors of the current review; the study examined the effects of increasing gasoline prices on air quality in the ten most populous cities of Iran and its impact on population health (more information on the methods and findings can be found in the **Supplementary Material**).

3.4. Summary of findings

This study reviews the chain of connections between fossil fuel pricing interventions, energy consumption, local air pollution, and population health. The evidence supports that interventions that increase fossil fuel consumer prices effectively reduce fossil fuel consumption and would impact population health by reducing mortalities and morbidities attributable to exposure to air pollutants. Interventions that increase consumer fuel prices have a wide range, but removing existing subsidies and setting additional taxes on energy consumption are the most common approaches. Previous studies also indicate that energy demand and consumption decrease with any rise in fossil fuel prices resulting from factors other than pricing policies (exogenous increases in prices) (Labandeira et al., 2017; Coady et al., 2019).

There was an association between increasing fossil fuel prices and decreasing concentrations of air pollutants. However, the effect sizes were heterogeneous for different air pollutants in different studies. Our findings (**Box 1** and **Supplementary Material**) illustrated that increasing gasoline prices have a greater impact on reducing NO_2 levels than PM concentrations in all selected cities. This is aligned with Tang et al. (2020) study that reported transportation as the primary source of NO_2 emissions in cities (55% in the USA) and suggested traffic control strategies to reduce transportation-related air pollutants, especially NO_2. Sicard et al. (2021) also reported that 52% of the NO_2 emission reduction in Southern European cities resulted from decreased road and non-road transport. On the other hand, PM emissions have several sources, and controlling PM emissions requires cooperation among various departments and sectors; for example, equipping diesel cars with Diesel Particulate Filters (DPF) has been reported

Box 1. The effects of increasing gasoline price in Iran on air pollutant levels and their health-related outcomes: an evaluation using the AirQ+ model

Background: This study investigated the effect of increasing the gasoline price on its consumption, ambient air quality, and human health in Iran's ten most populous cities.

Methods: The data on air pollutants (PM_{10}, $PM_{2.5}$, and NO_2) and gasoline consumption were collected from 2014 to 2016 for ten populous Iranian cities. Reductions in concentrations of air pollutants were estimated for the scenarios of increasing gasoline prices by 50, 80, and 200%. Then, reductions in deaths and morbidities attributable to air pollution were estimated using the World Health Organization's AirQ+ model.

Findings: **Table 1** summarizes some of the characteristics of the cities studied, the effects of an 80% increase in gasoline price on air pollutants (NO_2, $PM_{2.5}$, and PM_{10}), and their impact on mortality. More details about the methodology and findings of the study, including the results of alternative scenarios of 50 and 200% increase in gasoline price, are available in the **Supplementary Material.**

Table 1.
Summary of the effects of an 80% increase in gasoline price on air quality and mortality in the ten most populous cities of Iran.

City Name	Population (Million)	Density (1000/KM^2)	Baseline Mortality; All Causes (+30 Years)	PM2.5 (μg/m3)		PM10 (μg/m3)		NO_2 (μg/m3)		Averted Mortality per 100,000, All Causes (+30 Years) by 80% PIS
				Before	80% PIS	Before	80% PIS	Before	80% PIS*	
Tehran	8.74	12.0	754	36.6 (±8.39)	31.3 (±4.83)	68.8 (±12.2)	60.6 (±10.2)	105 (±18.5)	81.7 (±8.33)	23.5 (15.4-31.0)
Mashhad	3.37	9.61	311	31.1 (±8.95)	29.1 (±5.53)	75.4 (±17.9)	71.7 (±13.4)	21.3 (±17.3)	14.7 (±6.51)	3.81 (2.49-5.04)
Isfahan	2.24	4.07	591	38.3 (±10.0)	35.8 (±4.12)	72.1 (±21.7)	68.5 (±10.1)	20.9 (±7.46)	12.7 (±7.20)	8.79 (5.74-11.6)
Karaj	1.97	12.2	496	30.3 (±7.07)	28.0 (±4.86)	61.0 (±18.1)	57.8 (±9.81)	47.1 (±21.3)	38.2 (±6.26)	6.90 (4.51-9.13)
Shiraz	1.87	7.79	673	31.9 (±8.87)	29.9 (±4.17)	63.3 (±20.3)	60.8 (±10.0)	54.4 (±40.4)	44.9 (±5.55)	8.09 (5.28-10.7)
Tabriz	1.56	4.81	978	19.7 (±4.82)	16.7 (±4.10)	NM	NM	18.6 (±12.0)	7.61 (±7.05)	18.0 (11.7-23.7)
Ahvaz	1.30	7.04	137	65.7 (±40.4)	62.6 (±4.57)	165 (±87.7)	160 (±11.1)	43.7 (±22.2)	36.0 (±5.66)	2.51 (1.65-3.32)
Qom	1.29	4.53	549	37.8 (±20.6)	37.4 (±4.83)	NM	NM	NM	NM	1.45 (0.950-1.92)
Kermanshah	1.08	11.3	735	54.6 (±21.6)	52.0 (±6.32)	94.6 (±36.9)	91.5 (±14.1)	21.8 (±12.0)	16.3 (±6.09)	11.4 (7.46-15.1)
Urmia	1.04	9.91	454	32.8 (±11.0)	30.5 (±4.25)	77.5 (±27.9)	74.1 (±8.97)	13.7 (±8.72)	7.11 (±6.73)	6.10 (3.99-8.07)

* 80% Increase in Gasoline Price Scenario

as more effective in reducing PM emissions in urban areas compared to the increasing price (Mohammadiha et al., 2018). Long-term drought and mismanagement of water resources also have important effects on dust and PM in specific locations; for instance, the severe shrinking of Lake Urmia (an endorheic salt lake in the Northwest of Iran) and disruption of natural swamps such as Gavkhuni (Central Iran), and seasonal lake or Hamun of Jaz-Murian (Southeast of Iran), due to human interferences are related to increasing local levels of air pollutants, especially PM (Hosseini and Shahbazi, 2016).

It is evident that the external costs associated with fossil fuel consumption are often overlooked, given that many countries continue to provide subsidies for fossil fuels. This implies that they not only fail to employ effective pricing interventions to mitigate local air pollution and health impacts related to fossil fuels but also encourage increased usage by offering subsidies (Romanello et al., 2022). On the other hand, existing fossil fuel subsidies in numerous countries are pro-rich, contradicting the primary purpose of subsidies, which is to support the poorest individuals. For instance, a study conducted in Mexico illustrated a familiar trend where gasoline consumption increases as one moves from the poorest to the richest decile of households. This pattern underscores that the wealthiest households derive greater benefits from subsidized fuel than the less affluent population (Azcona et al., 2018). Despite this reality, implementing interventions to decrease fuel subsidies, particularly those lacking clear accompanying measures such as establishing alternative subsidies (e.g., for clean public transportation or food), may face opposition from the majority of the population. In Iran, for example, a sudden hike in gasoline prices during the fall of 2019 led to widespread social unrest across the nation (Mamipour et al., 2023), which ended up in bloody suppression. This is mainly because many of the households and businesses in countries with highly subsidized fuel are financially dependent on the low fuel prices; civil society and real representatives of the population should be wholly involved in policy-making processes to facilitate a smooth shift from the pro-rich

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strategy of subsidizing fossil fuels with substantial negative environmental and health impact to alternative policies that improve population health, welfare, and equity.

3.5. Improving energy efficiency and transition to clean alternative fuels

Improving energy efficiency is an important alternative to providing subsidized fossil fuels without sacrificing the population's quality of life. Generalizing access to and expanding the use of public transportation, especially in condensed Metropolitan areas, has a huge impact on air pollution and traffic congestion (Bailey et al., 2008). Replacing outdated engines with more efficient new technologies, such as hybrid self-charging engines, which are not necessarily more expensive, is also very important (Reich, 2012; Woody et al., 2022). Beyond improving energy efficiency, there exist several alternative fuels that are more environmentally friendly compared to fossil fuels. Biofuels, such as biodiesel and bioethanol, have been successfully utilized in many countries. They are effective and efficient and hold potential as a breakthrough, particularly as a parallel strategy during the expansion of public transportation systems (Azad et al., 2015). Electric vehicles are growing worldwide, especially in high-income countries; however, they can only be considered as clean if the electric energy itself has been generated by a clean source such as solar energy. Electric vehicles powered by coal electricity are amongst the range of internal combustion energy vehicles, and even worse, based on their SO_x (Hawkins et al., 2012). Also, there are other concerns, especially about the batteries of hybrid and electric cars and their potential environmental consequences.

3.6. Limitations

Conditions and characteristics of each location and population are different from others; this means that the effects of fuel pricing interventions on consumption, air quality, and health could vary between different settings and even within a country. The findings of this study should be cautiously used for new settings and should be followed by an assessment of the impact on equity.

This study was not a comprehensive and systematic review of all available sources of information. Although we tried to include important sources of information, it suffers from the limitations of a non-systematic review.

4. Conclusions

This review study demonstrates the effects of escalating fossil fuel prices on reducing consumption, air pollution, and mortalities and morbidities attributable to air pollution. Considering the external costs of fossil fuels through environmental, climate, traffic congestions and accidents, and population health, the real costs of fossil fuels are much higher than their retail price. An increase in fossil fuel prices should prompt a transition to cleaner alternatives, particularly by improving energy efficiency through measures like subsidizing public transportation and replacing outdated technologies. Additionally, adopting climate-friendly fuels such as biofuels should be prioritized.

Acknowledgments

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Supplementary Material

Estimation of the effects of increasing gasoline prices on air quality and health outcomes in the 10 most populous cities of Iran

S1. Study population

We studied the ten most populous Iranian cities: Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Karaj, Qom, Kermanshah, and Urmia. The cities have a population from 1,040,565 in Urmia to 8,737,510 in Tehran. The total population in these cities during the study period was estimated to be 24,473,855, about 41% of the country's urban population. The vulnerable population groups were categorized into those under 5 and equal or more than 30 yr old because the effect of pollutants and related diseases can be interrupted well for such groups. The characteristics of each city are provided in **Table S1**.

Table S1.
The characteristics of the studied cities.

City	Population	The number of households	Area (Km^2)	Population ≥ 30 yr (%)	Population < 5 yr old (%)
Tehran	8,737,510	2,924,208	730	50.69	8.78
Mashhad	3,372,660	1,021,068	351	49.81	9.17
Isfahan	2,243,249	707,870	551	50.26	8.98
Karaj	1,973,470	623,801	162	50.64	8.93
Shiraz	1,869,001	567,567	240	51.82	8.69
Tabriz	1,558,693	497,898	324	51.79	8.76
Ahvaz	1,302,591	362,480	185	50.63	8.97
Qom	1,292,283	383,532	285	51.96	9.25
Kermanshah	1,083,833	323,291	96	51.37	8.92
Urmia	1,040,565	304,306	105	49.89	9.11
Total	24,473,855	7,716,021	2,789	50.90	8.87

Source: Statistical Centre of Iran (Census 2016 - Detailed Results).

S2. Data collection

We considered three gasoline price increase scenarios: 50, 80, and 200% of the current price. It should be noted that the current price was about 0.077 USD/L, which increased to about 0.11, 0.14, and 0.23 USD/L in the respective scenarios. At the time of this study, USD 1 was equal to 40,000 Rials. The first scenario was selected because, at the start of our study the price was increased by 50%. The second scenario was selected as it had been found to be the most cost-effective one, according to the preliminary economic studies. And the last scenario was considered as the highest applicable price. We estimated the impact of each scenario on the levels of a set of air pollutants and their human health impacts using the Air Q+ model. The study was conducted from 21 March 2014 to 20 March 2017, during which the related data, in the form of either pollutants or outcomes, were available.

S2.1. Air pollution data

The hourly levels of air pollutants of PM_{10}, $PM_{2.5}$, and NO_2 for the ten cities were obtained from the publicly available online platforms of Iran's Department of Environment and Tehran's Air Quality Control. These pollutants were selected as they were more related to fuel consumption, accessible from the air quality measurement systems, and available for the population considered as well as for the area studied. Data management and cleaning were performed based on the Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe (Aphekom) (Moshammer et al., 2009). Air pollutant level data for at least two stations were used for each city. The stations with more than 25% missing data (at 24 h) or a correlation indicator (namely, the R-squared, R^2, of the regression of predicted on observed) lower than 0.60 were excluded from the study. It should be noted that the eighteen-hour valid data was accessible for each day. In order to calculate the daily mean concentration, the 24 h average and 1 h maximum concentration levels were used for PM and NO_2, respectively (Moshammer et al., 2009).

The gasoline consumption level over different time intervals was predicted using a linear model. Moreover, a linear mixed-effects model (**Eq. 1**) was used to consider the geographical and cultural differences between cities. Considering the scenarios of gasoline consumption increases, the air pollutants' levels for each city were estimated using **Equation S1** based on the gasoline consumption data (i.e., estimated values for gasoline price increase scenarios). In the present study, the R^2 between estimated and observed data was 0.79 for one-third of the data that were not used for estimation purposes, showing that the model fitting was adequate. PM_{10} data for Qom and Tabriz were excluded because they did not meet the Aphekom criteria. Therefore, the health effects of PM_{10} were not analyzed for Qom and Tabriz. Also, the health effects of NO_2 were not analyzed for Qom because of the unavailability of NO_2 data. The daily mean values of the temperature (˚C), relative humidity (%), and wind speed (meters per second, m/s) were obtained from Iran's Meteorological Organization and then were applied for investigation of the meteorological parameter effects.

$$y_{ij} = \beta_0 + \sum \beta_{ij} X_{ij} + \gamma + \varepsilon \qquad \text{Eq. S1}$$

where, y_{ij}, β_0, β_{ij}, X_{ij}, γ, and ε are response, intercept, fixed effect parameters, fixed effect variables, random effect variables, and residual, respectively.

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S2.2. Health effects

The following outcomes were considered in the long-term exposure to $PM_{2.5}$: the mortality rates due to ischemic heart disease (IHD; people > 25 years), lung cancer (LC; people > 30 yr), chronic obstructive pulmonary disease (COPD; people > 30 yr), and acute lower respiratory tract infection (ALRI; people < 5 years). Besides, the mortality rate attributed to long-term exposure to PM_{10} was estimated for live-born infants. For NO_2, all the related mortalities, irrespective of the causes of death, were considered.

The number of deaths due to target health impacts in the studied cities was received from the Center of Network Development Management of the Ministry of Health and Medical Education for the whole of the studied years. International classification of disease, 10th revision (ICD-10) codes of I20-I25, C33-34, J40-J44, and J20-J22 were used for the cases of IHD, LC, COPD, and ALRI, respectively.

S3. Health risk assessment using the WHO Air Q+ model

As stated, the Air Q+ model was applied for quantitative estimation of health effects associated with air pollution under three scenarios of gasoline price increase (50, 80, and 200 %). The effects of air pollutants (PM10, PM2.5, and NO_2, all as $\mu g/m^3$) were estimated using the Air Q2.2.3 version, updated in 2019 by the WHO European Centre for Environment and Health. Population attributable fraction (PAF) of mortalities due to exposure the PM_{10}, $PM_{2.5}$, NO_2, and O_3 at levels higher than the WHO thresholds were also estimated. The number of health outcomes attributed to air pollutants was estimated using **Equation S2**:

$$E = BI \times PAF \qquad \text{Eq. S2}$$

where BI denotes a certain baseline incidence of the selected health endpoint in the population, and PAF is the population attributable fraction computed by multiplying the population (P) and the relative risks, as shown in the following equation (**Eq. S3**):

$$PAF = \frac{P_{pop} \times (RR - 1)}{P_{pop} \times (RR - 1) + 1} \qquad \text{Eq. S3}$$

where P_{pop} is the proportion of exposed people in the entire study population, and RR refers to the risk (or rate) ratio.

The estimated values of baseline incidence and mortality rates for cities are summarized in **Table S2** (Faridi et al., 2018). Relative risk values were obtained from other studies (Burnett et al., 2014) and RR suggested by WHO, which is available on Air Q+ software (Mudu et al., 2016). All these data were later used as inputs of the model.

Table S2.
Baseline incidence (BI) range rates were used in the current study by cities (per 10^5 capita).

City	BI for LC*	BI for ALRI Mortality	BI for COPD Mortality	BI for LC Mortality	Post neonatal infant Mortality	Mortality (All causes (+30 yr)	Mortality (All causes)
Tehran	8.74	2.58	9.98	13.64	18.53	754	416
Mashhad	8.23	1.67	6.06	4.22	11.51	311	191
Isfahan	8.35	3.02	12.32	12.76	15.14	591	327
Karaj	7.19	2.86	5.63	9.28	15.34	496	277
Shiraz	8.08	4.83	14.96	10.41	25.42	673	392
Tabriz	10.26	5.79	33.36	21.40	24.70	978	542
Ahvaz	9.59	3.46	1.13	2.13	4.16	137	81
Qom	8.74	3.49	10.63	4.05	17.87	549	317
Kermanshah	6.89	8.32	14.33	12.37	27.75	735	428
Urmia	12.37	1.08	15.09	10.37	11.52	454	285

* LC: Lung Cancer; COPD: Chronic Obstructive Pulmonary Disease.

S4. Findings

S4.1. Level of air pollutants

The annual mean value of the air pollutant levels ($\mu g/m^3$) in ten crowded cities of Iran during the study period (2014-2016) before and after increases in gasoline price (by 50, 80, and 200%) are listed in **Table S3**. As demonstrated, the mean levels of both PM_{10} and $PM_{2.5}$ in all cities and under all scenarios were higher than the WHO standards. NO_2 levels decreased significantly under the price-rising scenarios in all investigated cities except for Tehran; NO_2 concentrations fell in all cities to the acceptable range based on the WHO standards (i.e., under 40 $\mu g/m^3$). Considering these findings, along with the difference between the human body's susceptibility, it seems that the present guideline values may not be enough for human health protection (Nadali et al., 2021).

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Table S3.
The annual mean value of the air pollutant levels (μg/m^3) in ten populous cities before and after increasing of gasoline price (by 50, 80, and 200 %).

City	**$PM_{2.5}$**				**PM_{10}**				**NO_2**			
	Before	**50% PIS**	**80% PIS**	**200% PIS**	**Before**	**50% PIS**	**80% PIS**	**200% PIS**	**Before**	**50% PIS**	**80% PIS**	**200% PIS**
Tehran	36.60	32.63	31.34	28.13	68.75	62.75	60.6	55.25	105.64	88.41	81.73	65.02
Mashhad	31.11	29.44	29.06	28.13	75.36	72.36	71.74	70.17	21.28	16.62	14.67	9.80
Isfahan	38.25	36.10	35.76	34.59	72.06	69.12	68.54	67.11	20.90	14.50	12.70	8.22
Karaj	30.33	28.26	28.00	27.38	60.96	58.21	57.79	56.75	47.08)	39.46	38.17	34.94
Shiraz	31.89	30.15	29.88	29.18	63.30	61.26	60.79	60.72	54.37	46.34	44.90	41.29
Tabriz	19.73	16.83	16.65	16.21	NA*	NA	NA	NA	18.59	8.51	7.61	5.34
Ahvaz	65.71	62.79	62.63	62.22	165.52	160.69	160.43	159.76	43.73	36.84	36.00	33.92
Qom	37.83	37.54	37.39	37.01	NA	NA	NA	NA	NA	NA	NA	NA
Kermanshah	54.64	52.14	52.04	51.8	94.57	91.62	91.46	91.05	21.80	16.78	16.27	15.02
Urmia	32.76	30.61	30.51	30.25	77.46	74.29	74.12	73.7	13.69	7.64	7.11	5.80
Annual WHO guidelines	**10 μg/m^3**				**20 μg/m^3**				**40 μg/m^3**			

* NA: Baseline measure was not available; PIS: Price Increase Scenario.

S4.2. Health effects of exposure to the pollutants

S4.2.1. $PM_{2.5}$ exposure

By sorting $PM_{2.5}$-related data for all cities involved after the gasoline price rising, it can be observed that 1308 (896-1728), 1,619 (1,061-2,140), and 2,405 (1,578-3,165) deaths/yr would be averted for people > 30 yr, during the respective scenarios (**Table S4**). In other words, a total of 0.49 (6.86-13.86), 13.00 (8.52-17.17), and 19.28 (12.66-25.39) death rate per 100,000 can be averted. The latter for children < 5 yr due to ALRI was estimated to be 0.04 (0.03-0.05), 0.05(0.03-0.06), and 0.08(0.04-0.09), respectively (**Table S4**).

Table S4.
The estimated decrease in the mortality rate (per 100,000) attributed to $PM_{2.5}$ exposure after gasoline price rising.

City	**50% PIS**	**80% PIS**	**200% PIS**	**50% PIS**	**80% PIS**	**200% PIS**
	Mortality, all causes (+30 yr)			**Mortality due to ALRI* (CI 95%)**		
Tehran	17.79 (1.65- 23.49)	23.48 (15.40-30.97)	37.45 (24.64-49.24)	0.05 (0.03-0.07)	0.07 (0.04-0.09)	0.12 (0.07-0.15)
Mashhad	3.11 (2.03-4.11)	3.81 (2.49-5.04)	5.53 (3.61-7.30)	0.02 (0.01-0.02)	0.02 (0.02-0.02)	0.03 (0.02-0.03)
Isfahan	7.59 (4.96-10.05)	8.79 (5.74-11.62)	12.87 (8.42-17.00)	0.03 (0.02-0.04)	0.04 (0.02-0.05)	0.06 (0.03-0.07)
Karaj	6.14 (4.01-8.12)	6.90 (4.51-9.13)	8.72 (5.71-11.53)	0.04 (0.02-0.04)	0.04 (0.03-0.04)	0.05 (0.04-0.06)
Shiraz	7.01 (4.58-9.27)	8.09 (5.28-10.70)	10.88 (7.12-14.39)	0.05 (0.03-0.06)	0.06 (0.03-0.07)	0.08 (0.05-0.09)
Tabriz	16.91 (11.06-22.35)	17.95 (11.74-23.73)	20.49 (13.41-27.07)	0.14 (0.09-0.17)	0.15 (0.10-0.18)	0.17 (0.12-0.21)
Ahvaz	2.39 (1.56-3.15)	2.51 (1.65-3.32)	2.85 (1.86-3.76)	0.03 (0.02-0.04)	0.03 (0.02-0.04)	0.04 (0.02-0.05)
Qom	0.96 (0.62-1.27)	1.45 (0.95-1.92)	2.70 (1.76-3.58)	0.01 (0.00-0.01)	0.01 (0.00-0.01)	0.02 (0.01-0.02)
Kermanshah	10.97 (7.17-14.51)	11.41 (7.46-15.08)	12.45 (8.14-16.46)	0.08 (0.05-0.1)	0.08 (0.05-0.10)	0.09 (0.05-0.11)
Urmia	5.83 (3.82-7.72)	6.10 (3.99-8.07)	6.80 (4.45-9.00)	0.02 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.01-0.02)

* ALRI: Acute Lower Respiratory Infection, PIS: Price Increase Scenario.

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Moreover, 0.20 (0.09-0.30), 0.24 (0.11-0.37), and 0.36(0.17-0.53) LC incidence rate/100,000 would be decreased for people > 30 yr, when the price of gasoline increased by 50, 80, and 200%, respectively. The respective values for LC death rate and people > 25 yr were estimated to be 0.13 (0.1-0.16), 0.16 (0.12-0.20), and 0.25 (0.18-0.30) per 100,000 individuals, respectively. For the same group, the estimated values were 0.17, 0.24, and 0.37 for COPD; 0.47, 0.59, and 0.90 for IHD; and 41(20-77), 51 (22-94), and 75 (33-124) stroke, during three respective scenarios (**Table S5**).

Table S5.
The estimated numbers of averted mortality due to COPD and lung cancer (LC), and averted incidence of LC (per 100,000) attributed to PM$_{2.5}$ exposure after gasoline price rising.

Cities Name	PM$_{2.5}$								
	Incidence of LC (CI 95%)			Mortality due to COPD* (CI 95%)			Mortality due to LC (CI 95%)		
	50% PIS	80% PIS	200% PIS	50% PIS	80% PIS	200% PIS	50% PIS	80% PIS	200% PIS
Tehran	0.29 (0.14-0.44)	0.39 (0.18-0.58)	0.62 (0.29-0.92)	0.16 (0.12-0.23)	0.22 (0.16-0.32)	0.37 (0.26-0.57)	0.21 (0.16-0.25)	0.28 (0.21-0.34)	0.47 (0.35-0.57)
Mashhad	0.12 (0.05-0.18)	0.14 (0.07-0.22)	0.21 (0.01-0.32)	0.05 (0.03-0.07)	0.06 (0.04-0.09)	0.08 (0.06-0.13)	0.03 (0.03-0.04)	0.04 (0.03-0.05)	0.06 (0.04-0.07)
Isfahan	0.15 (0.07-0.23)	0.18 (0.08-0.27)	0.26 (0.12-0.39)	0.11 (0.7-0.15)	0.12 (0.08-0.17)	0.18 (0.12-0.25)	0.10 (0.08-0.12)	0.12 (0.09-0.14)	0.21 (0.13-0.21)
Karaj	0.13 (0.06-0.19)	0.14 (0.07-0.22)	0.18 (0.08-0.27)	0.05 (0.04-0.09)	0.06 (0.04-0.10)	0.08 (0.06-0.12)	0.08 (0.06-0.1)	0.09 (0.07-0.11)	0.12 (0.09-0.15)
Shiraz	0.12 (0.05-0.18)	0.14 (0.06-0.21)	0.19 (0.09-0.28)	0.11 (0.08-0.19)	0.13 (0.10-0.23)	0.18 (0.13-0.32)	0.07 (0.06-0.09)	0.08 (0.07-0.11)	0.12 (0.09-0.15)
Tabriz	0.25 (0.12-0.38)	0.27 (0.12-0.41)	0.31 (0.14-0.46)	0.65 (0.39-0.99)	0.69 (0.41-1.05)	0.80 (0.47-1.20)	0.35 (0.21-0.48)	0.37 (0.22-0.51)	0.43 (0.26-0.59)
Ahvaz	0.24 (0.11-0.36)	0.25 (0.12-0.38)	0.28 (0.13-0.43)	0.00 (0.01-0.01)	0.01 (0.01-0.01)	0.01 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.02-0.03)
Qom	0.02 (0.01-0.03)	0.03 (0.02-0.05)	0.06 (0.03-0.09)	0.02 (0.01-0.02)	0.02 (0.02-0.02)	0.04 (0.03-0.05)	0.01 (0.00-0.01)	0.01 (0.00-0.01)	0.02 (0.01-0.02)
Kermanshah	0.15 (0.07-0.22)	0.15 (0.07-0.23)	0.17 (0.08-0.25)	0.11 (0.08-0.18)	0.11 (0.08-0.19)	0.12 (0.09-0.21)	0.09 (0.08-0.11)	0.10 (0.08-0.11)	0.11 (0.09-0.12)
Urmia	0.23 (0.10-0.34)	0.24 (0.11-0.36)	0.26 (0.12-0.40)	0.14 (0.1-0.24)	0.15 (0.10- 0.20)	0.17 (0.12-0.28)	0.10 (0.07-0.11)	0.10 (0.07-0.12)	0.11 (0.08-0.13)

* COPD: Chronic Obstructive Pulmonary Disease; LC: Lung Cancer; PIS: Price Increase Scenario.

S4.2.2. PM$_{10}$ exposure

For all cities except Qom and Tabriz, 104 (53-179), 133 (68-226), and 197 (102-337) death/yr would be decreased post-neonatal infants (0-29 d), under scenarios 1, 2, and 3, respectively. In fact, the relative total death rate would be decreased by 0.25 (0.13-0.43), 0.32 (0.16-0.55), and 0.48 (0.25-0.82) cases per 1000 live-born infants, respectively (**Table S6**).

Table S6.
The estimated decrease in the relative number of post-neonatal infant mortality (death/100.000) attributed to PM$_{10}$ exposure after gasoline price rising.

City	PM10		
	50% PIS	80% PIS	200% PIS
Tehran	0.43 (0.22-0.74)	0.58 (0.30-0.99)	0.96 (0.49-1.62)
Mashhad	0.13 (0.07-0.23)	0.16 (0.08-0.28)	0.23 (0.12-0.40)
Isfahan	0.17 (0.09-0.30)	0.21 (0.11-0.36)	0.29 (0.15-0.50)
Karaj	0.16 (0.08-0.28)	0.19 (0.10-0.33)	0.25 (0.13-0.43)
Shiraz	0.20 (0.10-0.35)	0.25 (0.13-0.43)	0.26 (0.13-0.44)
Tabriz	NA*	NA	NA
Ahvaz	0.08 (0.04-0.13)	0.08 (0.04-0.14)	0.09 (0.05-0.16)
Qom	NA	NA	NA
Kermanshah	0.32 (0.16-0.55)	0.34 (0.17-0.58)	0.38 (0.19-0.65)
Urmia	0.14 (0.07-0.24)	0.15 (0.08-0.26)	0.17 (0.09-0.29)

* NA: Baseline measure was not available; PIS: Price Increase Scenario.

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S4.2.3. NO_2 exposure

For whole studied cities except Qom, when it comes to NO_2, a number of 3,662 (1,743-5,570), 4,779 (2,285-7,226), and 7,460 (3,617-11,124) death/yr would be averted under the scenarios, which are corresponding to 15.80 (7.51-24.02), 20.61 (9.85-31.17), and 32.18 (15.60-47.98) total death rate per 100,000 population (**Table S7**).

Table S7.
The estimated decrease in the number mortality attributed to NO_2 exposure after gasoline price rising.

City	NO_2		
	50% PIS	**80% PIS**	**200% PIS**
Tehran	27.83 (13.27-42.17)	38.11 (18.31-57.35)	62.65 (30.62-92.66)
Mashhad	3.54 (1.67-5.44)	5.01 (2.36-7.67)	8.61 (4.08-13.13)
Isfahan	8.30 (3.92-12.73)	10.60 (5.01-16.22)	16.24 (7.71-24.74)
Karaj	8.35 (3.94-12.79)	9.74 (4.61-14.90)	13.19 (6.26-20.09)
Shiraz	12.45 (5.88-19.05)	14.64 (6.93-22.37)	20.07 (9.53-30.55)
Tabriz	21.51 (10.19-32.85)	23.39 (11.09-35.69)	28.10 (13.35-42.77)
Ahvaz	2.21 (1.04-3.39)	2.48 (1.17-3.79)	3.13 (1.48-4.78)
Qom	NA*	NA	NA
Kermanshah	8.55 (4.02-13.12)	9.41 (4.43-14.43)	11.50(5.43-17.63)
Urmia	6.84 (3.23-10.50)	7.44 (3.51-11.40)	8.89(4.20-13.61)

* NA: Baseline measure was not available; PIS: Price Increase Scenario.

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