AIR POLLUTION IN TEHRAN: HEALTH COSTS, SOURCES, AND POLICIES

Martin Heger and Maria Sarraf

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ABBREVIATIONS

AAP	Accountability to Affected Populations
AQCC	Air Quality Control Company
AQI	Air Quality Index
BRT	Bus Rapid Transit
CNG	compressed natural gas
CO	carbon monoxide
DOE	Department of Environment
DPF	diesel particulate filter
GBD	Global Burden of Disease
HDV	heavy-duty vehicles
IER	Integrated Exposure-Response
IHME	Institute for Health Metrics and Evaluation
IRI	Islamic Republic of Iran
LEZ	low emissions zone
LNG	liquefied natural gas
MDV	medium-duty vehicles
NO	nitrogen dioxide
OECD	Organization for Economic Co-operation and Development
PM	particle matter
SO	sulfur dioxide
VSL	Value of Statistical Life
WHO	World Health Organization
WTP	Willingness to Pay

INTRODUCTION

Tehran, the capital of the Islamic Republic of Iran (IRI), is located in the north of the country with a population of about 8.5 million. The population can reach over 12.5 million during the day, with people from nearby cities commuting daily to Tehran for work (Shahbazi et al. 2016). There are more than 17 million vehicular trips per day in Tehran (Hosseni and Shahbazi 2016), and many of the vehicles have outdated technology. Thus, the air in Tehran is amongst the most polluted in the world.[1] Topography and climate add to the pollution problem. Tehran is at a high altitude and is surrounded by the Alborz Mountain Range, which traps polluted air. Temperature inversion, a phenomenon particularly occurring during the winter months, prevents the pollutants from being diluted. Several recent trends indicate that reducing air pollution will not be straight forward: rapid population growth (partially due to migration from other cities), industrial development, urbanization, and increasing fuel consumption are pressure points for clean air in Tehran.

To design an effective approach to air pollution management, it is important to diagnose the problem, determine its sources, and identify affordable and sustainable solutions (World Bank 2004). This discussion paper provides an overview of the seriousness of air pollution in the city of Tehran; quantifies its impact in terms of health and economic costs; identifies the sources of pollution; and, finally, provides a framework to address the problem.

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[1] *Source:* World Bank staff based on data from the World Health Organization (WHO), 2016.

CHAPTER ONE
OVERVIEW OF AMBIENT AIR POLLUTION IN TEHRAN

Measuring air pollution. There are various pollutants in the air. The most commonly measured are:

- » particulate matter (PM),
- » carbon monoxide (CO),
- » nitrogen dioxide (NO_2),
- » sulfur dioxide (SO_2), and
- » ozone (O_3).[2]

Particulate matter (PM) is defined as fine inhalable particles that are suspended in the air, regardless of the size of the particle. The two most common size fractions of PM measures are PM_{10} and $PM_{2.5}$. PM_{10}, also referred to as "coarse PM," are particles of 10 micrometers in diameter or smaller; $PM_{2.5}$, also referred to as "fine PM" are a subset of those particles, namely those that are 2.5 micrometer in diameter or smaller. Sources of PM_{10} include crushing or gridding operations and dust stirred up by vehicle and roads.[3] $PM_{2.5}$, on the other hand, originates from all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.[4] $PM_{2.5}$ poses the most severe health impacts out of all measurable particle sizes, because the fine particles can get deep into the alveolar region of the lungs and even into the bloodstream.[5] Therefore, in this discussion paper, we primarily focus on $PM_{2.5}$. However, for many analyses only PM_{10} measurements are available (both measures are highly correlated), which is why we sometimes present results for PM_{10}. We focus so prominently on this single pollutant because it has shown to be the most consequential

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[2] These are only the commonly measured and regulated pollutants. There are many others that are not regularly measured, but that are nonetheless hazardous, including benzene, toluene, xylene, radon, and heavy metals. See Amini et al., 2017.

[3] *Source:* www.airnow.gov

[4] *Source:* www.airnow.gov

[5] Studies indicate that ultrafine particles ($PM_{0.1}$) cause the most severe health effects. Due to difficulty of measuring $PM_{0.1}$ and a lack of relevant data, we work with $PM_{2.5}$ data.

FIGURE 1. ANNUAL CONCENTRATION OF PM_{10} IN MEGACITIES (µg/m³)
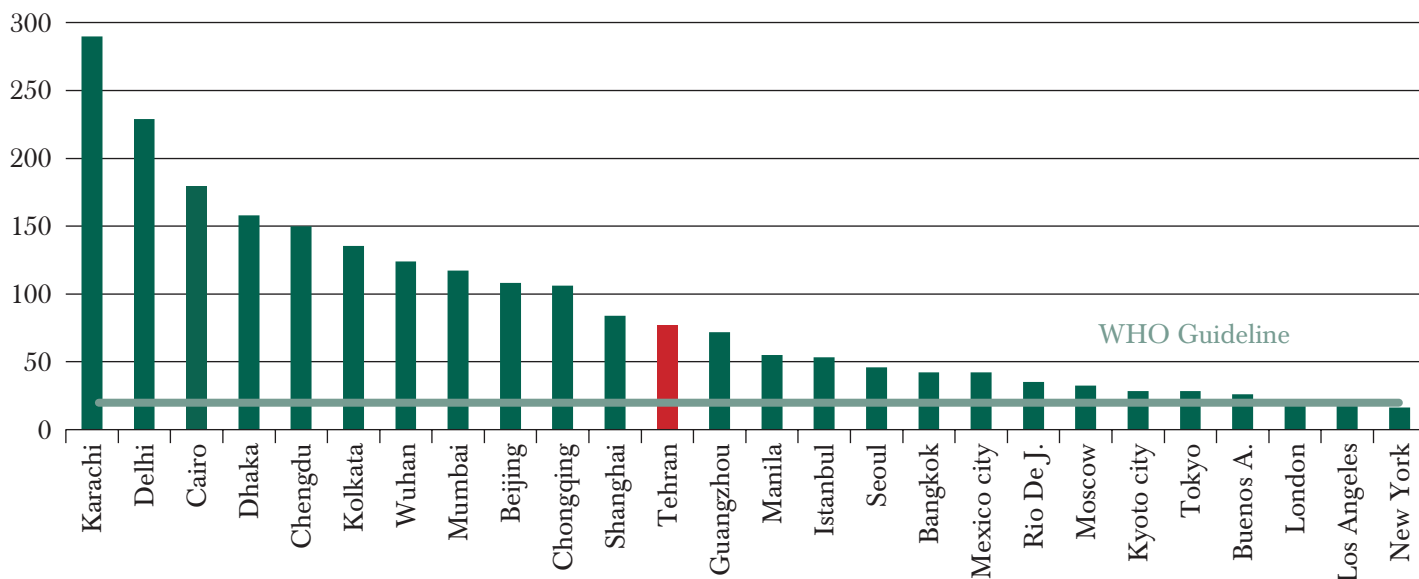
Source: WHO 2016

for health and economic effects by a large margin. Testament to the importance of PM is that all three global flagship reports on health and air pollution in 2016–by the World Bank, World Health Organization (WHO), and Organization for Economic Co-Operation and Development (OECD)–focused exclusively on $PM_{2.5}$. Moreover, the 2017 Lancet Commission Report on Pollution and Health also focused solely on $PM_{2.5}$.

Tehran is one of the most air polluted cities in the world. Tehran is ranked 12th among 26 megacities (see Figure 1) in terms of ambient PM_{10} levels. After Cairo, Tehran is the most polluted non-Asian megacity. In 2016, the annual ambient level of PM_{10} was estimated at 77 µg/m³ (micrograms per cubic meter). This is almost four times the WHO's recommended threshold of 20 µg/m³.

The annual mean concentration of $PM_{2.5}$ in Tehran was 32 µg/m³ in 2015/2016, more than three times the national standards and the Air Quality Guideline of the WHO, which are 10 µg/m³. These thresholds are set because there are close linkages between PM exposure and health mortality and morbidity effects, and the health effects are quite severe if these thresholds are surpassed. That said, these thresholds do not suggest that there is no damage to health at lower lev-els of exposure. The WHO thresholds are useful guidelines, but even smaller concentration levels have been identified to have health effects (Nachman 2016).

$PM_{2.5}$ CONCENTRATION AND STANDARDS

$PM_{2.5}$ (µg/m³) March 2015– March 2016	WHO Standards	Iran Standard
32	10	10

Sources: Tehran Air Quality Report 2016 and WHO AAP

Air Quality Measurement in Iran. The Department of Environment (DOE) and the Air Quality Company of Tehran Municipality (AQCC) follow an Air Qual-

ity Index (AQI) combining four pollutants: particulate matter, nitrogen dioxide, sulphur dioxide, and ozone. As indicated in Table 1, the index ranges from 0 to 500. In 1992, the DOE established the first air quality monitoring station in Iran. Currently there are thirty-nine stations in Tehran and 200 nationwide. These monitoring stations are operated by the DOE in the nation and by DOE and Tehran AQCC, a subsidiary of Tehran municipality, in Tehran.

TABLE 1. AIR QUALITY INDEX (AQI)

Code	AQI
Clean	0–50
Moderate	51–100
Unhealthy for sensitive group	101–150
Unhealthy	151–200
Very Unhealthy	201–300
Hazardous	301–500

Source: Tehran Air Quality Report 2016

Tehran had 111 unhealthy days (including 1 hazardous day) in 2015 (see figure 2). Due mostly to high levels of $PM_{2.5}$, the AQI reported 110 unhealthy[6] days and one day of hazardous condition, which is considered an emergency (AQCC 2016). Even though there is a general trend of decreasing air pollution, from 216 days that were classified as unhealthy in 2011 to 111 days in 2015, the current levels still offer much room for improvement.

Air pollution concentrations vary substantially within a year. The AQI varies over the course of a year in Tehran (see Figure 3). During autumn and winter, Tehran becomes more polluted. Atmospheric temperature inversion[7] worsens air pollution during that period. Spring and summer are usually less polluted. August, for example, was the cleanest month of the year in 2015. There are occasional dust storms at the end of spring and beginning of summer that increase PM concentrations and result in unhealthy air. The unhealthy days due to dust storms are relatively rare compared to those caused by combustion sources during the cold seasons.

Communication and public awareness. The Municipality of Tehran reports daily air quality measures in various locations across the city. This information is publicly available and can be obtained from AQCC website,[8] billboards across the city, free mobile apps for Android and IOS,[9] and in social media platforms such as Telegram and Instagram. Information about air quality at different stations, available daily and weekly, is provided; as well as educational information to increases awareness on number definitions related to air pollutants. These applications can send notifications when air quality is unhealthy. Moreover, in 2016/2017 an air quality forecasting system was put in place by AQCC. Air quality forecasts[10] for the coming 24-hours are channeled through various media to public.

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[6]For simplicity, in this paper "unhealthy" refers to the categories "unhealthy" and "unhealthy for sensitive groups" from the official Air Quality Index classification of Iran.

[7]Atmospheric temperature inversion: Normally, hot air rises. When temperature inversion occurs, a cooler layer of air comes after a warmer layer of air in the troposphere, which is the layer in the atmosphere that is closest to earth. The inversion essentially caps the air and prohibits its upward movement; therefore the diffusion of pollutants is limited, as they remain trapped in the lower levels of the troposphere.

[8]Please see: http://air.tehran.ir/airnow for more information

[9]Please see: "كفيت هواي تهران" for access to the mobile app

[10]Forecasts are available at: http://apfs.Tehran.ir

FIGURE 2. AIR QUALITY INDEX IN TEHRAN (2011–2015)
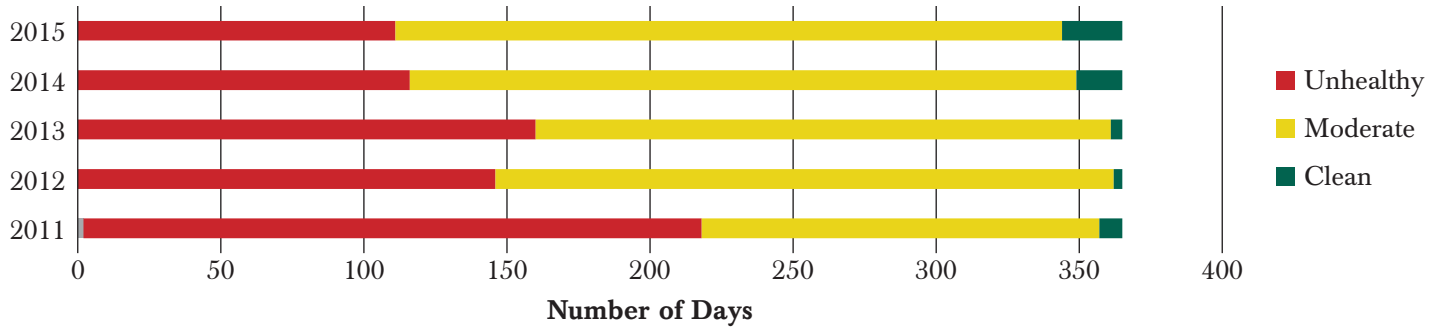
Source: AQCC 2016

FIGURE 3. MONTHLY CHANGES IN AQI IN TEHRAN (2015/2016)
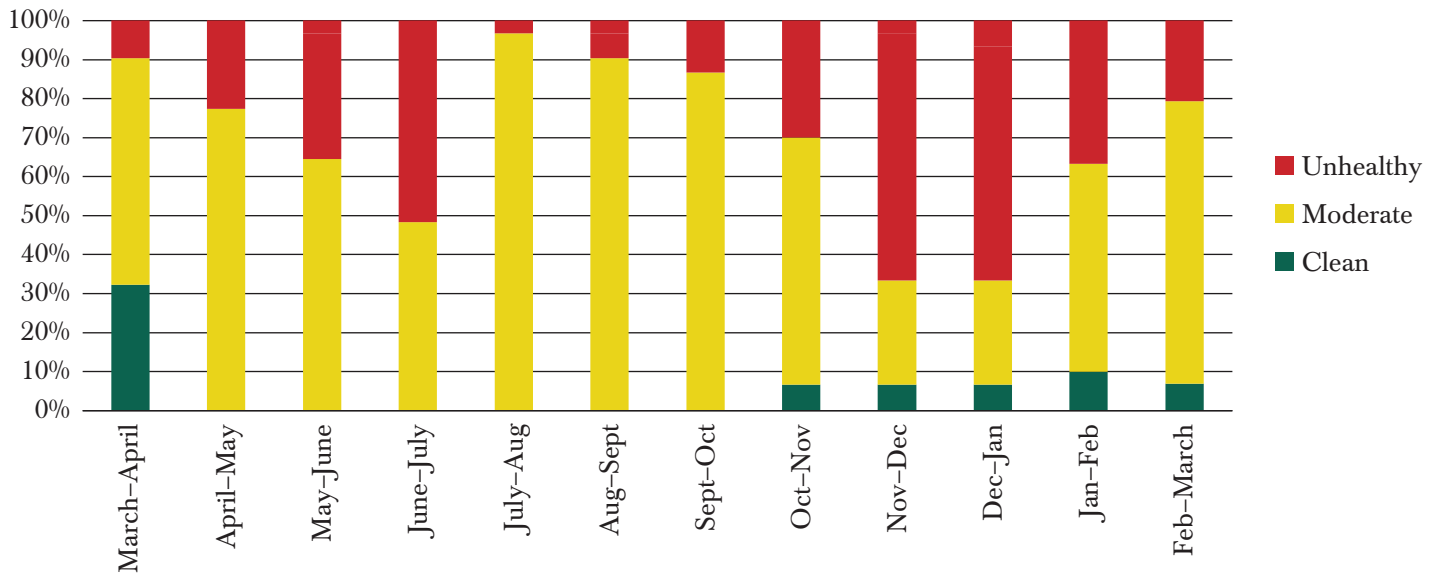
Source: AQCC 2016

CHAPTER TWO
HEALTH IMPACT AND ECONOMIC COST OF AIR POLLUTION IN TEHRAN

2.1 MORTALITY

Our research indicates that slightly more than 4000 people die prematurely from ambient $PM_{2.5}$ air pollution in Tehran per year. We arrived at this measure using the Global Burden of Disease (GBD) methodology and Integrated Exposure-Response (IER) functions, as outlined by the recent World Bank-Institute for Health Metrics and Evaluation (IHME) publication (Narain and Sall 2016). The GBD methodology predicts premature mortalities based on relative risk functions drawn from the epidemiological literature. The reference provided gives more information about the methodology.

We estimate that reducing ambient $PM_{2.5}$ concentrations to levels comparable to those of London (20 μg/m^3) would prevent about 1,300 premature deaths per year; and to levels comparable to those of New York City (15 μg/m^3) would prevent about 2000 premature deaths per year. As will be shown in the next section, most $PM_{2.5}$ originates from mobile sources (i.e., transport). Reducing traffic emissions alone by half would prevent about 750 premature deaths per year. We arrive at these estimates by tracing the values along the epidemiological IER function, as put forth by the GBD methodology from IHME. There is heterogeneity across countries, which is not captured by a single, universal IER function. This makes national epidemiological studies important in empirically validating the estimated health effects. Fortunately, a host of epidemiologic and public health studies have been carried out in Iran, which we review in this section.

2.2 MORBIDITY

It's not only about deaths: there are also many instances of respiratory and cardiovascular disease, among other illnesses, that could be avoided if Tehran were to move towards cleaner air. Iran has a strong tradition of excellent epidemiological research. There are countless scientific articles published on the morbidity effects of air pollution in Iran, and all of them point towards sizeable adverse consequences. Here we briefly review the most recent literature on the subject by Iranian scholars.

Air pollution is a major environmental risk factor for morbidity in Iran including diseases such as asthma, lung cancer, ventricular hypertrophy, Alzheimer's and Parkinson's diseases, autism, and retinopathy (Ghorani-Azam et al. 2016). Higher air pollution days resulted in more hospital admissions in Tehran (Khalilzadeh et al. 2009), and high $PM_{2.5}$ days lead to increased admissions to the emergency department, particularly for respiratory problems in Tehran (Shadi et al. 2014). Aside from respiratory problems, analyzing hospital admission and diagnoses in Iran also showed that air pollutants had a high correlation with acute strokes; and that long-term increases of $PM_{2.5}$ were related to ischemic strokes (Alimohammadi et al. 2015). A study looking at around 300 women in Tehran, and evaluating the correlation between ambient air pollution and spontaneous abortions in the first-trimester, found that there is also heightened risk of spontaneous abortion associated with increased PM levels (Moridi et al. 2014). A study in Isfahan, Iran showed how PM air pollution leads to hospitalization for respiratory diseases among children (Mansourian et al. 2010).

2.3 THE ECONOMIC COSTS OF MORTALITY AND MORBIDITY FROM AIR POLLUTION IN TEHRAN

The economic costs associated with air pollution in Tehran are estimated at USD 2.6 billion per year. Mortality and morbidity due to current level of air pollution in Tehran are estimated to cost the city's economy about USD $2.6 billion per annum (see Box 1 for detailed calculations). This estimate only considers human health effects, and therefore underestimates the total economic cost from air pollution. The total economic damage from air pollution would be much higher if one accounted for other impacts such as:

   » reduced agricultural productivity;
   » reduced visibility;
   » long-term damage to cultural sites and infrastructure;
   » reduced quality of life; and
   » education-days lost because of closed schools.

For instance, in mid-November 2016 authorities in Tehran closed schools for several days due to dangerous levels of pollution in the air. This not only affected the human capital formation of the pupils, but also the productivity of their parents, some of whom had to stay home from work to take care of their children.

Reducing air pollution leads to substantial reduction in economic costs. Per Figure 4, a reduction of $PM_{2.5}$ ambient air pollution to concentration levels comparable to Seoul, South Korea, would result in avoided economic costs of about USD 400 million per year for Tehran. A further decrease to concentration levels comparable to those of Mexico City would result in additional avoided costs of about USD 300 million per year; to London levels would avoid an additional USD 400 million; and to New York levels an additional USD 500 million. Overall, reducing air pollution concentration levels comparable to those of New York City would save the Tehran economy about USD 1.6 billion annually in avoided economic costs. These avoided costs can be used a low estimates for the benefits of pollution reduction, which may be compared to the costs of pollution policy actions.

BOX 1. ESTIMATING THE HEALTH IMPACTS OF AMBIENT AIR POLLUTION IN TEHRAN AND ASSOCIATED COSTS

Estimating mortality. Several epidemiological studies reveal strong correlations between long-term exposure to $PM_{2.5}$ and premature mortality (Apte et al. 2015; Pope et al. 2009 and 2011; Lim et al. 2012; Mehta et al. 2013; and Krewski et al. 2009). In particular, recent research associated $PM_{2.5}$ exposure with mortality related to four diseases in adults: ischemic heart disease, stroke, chronic obstructive pulmonary disease and lung cancer; as well as acute lower respiratory tract infections in children. Apte et al., (2015) produced integrated exposure-response functions that estimate the mortality risk for each health endpoint, age group, and $PM_{2.5}$ concentration. Using these functions, the paper estimates the number of premature deaths due to $PM_{2.5}$ in Iran.

The cost of mortality. This cost estimate is based on the Value of Statistical Life (VSL). This concept was the topic of numerous studies and meta-analyses (e.g. Biausque 2012; Lindjehm et al. 2011; OECD 2012). To derive the VSL for Iran, we use benefits transfer of a base VSL ranging between US$4.35 million and US$4.83 million (at 2011 market rates) (Narain and Sall 2016). These numbers reflect the median and the mean VSL estimates from a database of quality-screened Willingness to Pay (WTP) studies conducted in high-income OECD countries. The transfer is conducted based on the formula:

$$VSL_{IRAN} = VSL_{OECD} * \left[Y_{IRAN} / Y_{OECD} \right]^e$$

where VSL_{IRAN} is the VSL for Iran; VSL_{OECD} is the average base VSL estimate from the sample of WTP studies in OECD countries; Y_{IRAN} is GDP per capita for Iran; Y_{OECD} is the average GDP per capita for the base sample of OECD countries; and e is the income elasticity of the VSL. For low and middle-income countries, e varies from 1.0 to 1.4, with a central estimate of 1.2. Accordingly, the VSL for Iran was estimated in the range between US$470,000 and U$520,000, with an average of US$495,000 (updated to year 2016, at market rates).[11]

Cost of morbidity. The economic cost of morbidity includes resource costs (e.g., financial costs for avoiding or treating pollution-associated illnesses), opportunity costs (e.g., indirect costs from the loss of time for work and leisure) and disutility costs (e.g., the costs of pain, suffering or discomfort) (Hunt and Ferguson 2010). Due to the difficulty in estimating all types of costs in many countries, no standard method has been developed to value the overall cost of morbidity due to ambient air pollution (OECD 2014). However, based on the results of studies conducted in a few OECD countries, recent guidelines suggest that morbidity costs are approximately 10 percent mortality costs (Hunt et al. 2016; Narain and Sall 2016). In the absence of surveys on the willingness to pay to avoid pollution-related illnesses in Iran, the morbidity costs are estimated accordingly.

FIGURE 4. AVOIDED ANNUAL ECONOMIC COSTS ASSOCIATED WITH REDUCING $PM_{2.5}$ CONCENTRATIONS IN TEHRAN
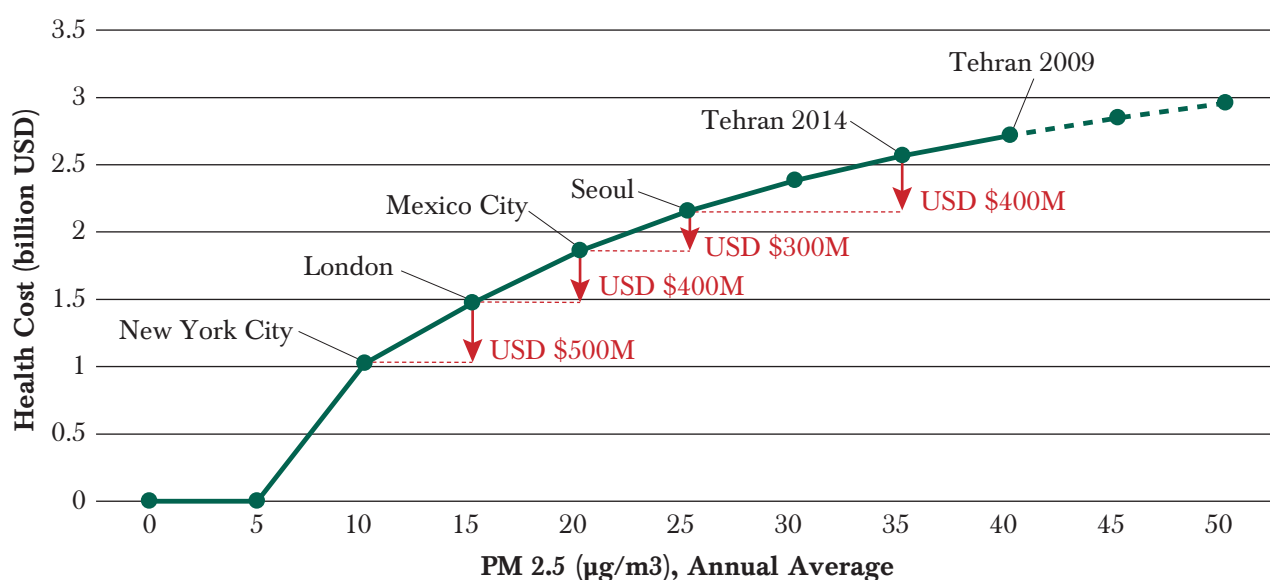
Sources: WHO AAP 2016 and World Bank-IHME 2016 data

[11]This is substantially lower than the VSL of US$2.6 million per capita provided for Iran by Ainy et al., 2014.

CHAPTER THREE
SOURCES OF AIR POLLUTION

3.1 MOBILE SOURCES ARE THE LARGEST CONTRIBUTOR TO AMBIENT PM AIR POLLUTION

The preponderance of PM emissions in Tehran originates from mobile sources. The largest share of PM emissions, roughly 70 percent, originates from mobile sources (vehicles). The remainder stems from non-traffic related emissions: 20 percent from energy conversion (including refineries and power plants), 7 percent from industries, 2 percent from household and commercial sources, and 1 percent from gas terminals. Because of their sizeable contribution to PM, we focus almost exclusively on mobile sources in this section.[12]

Particulate matter from dust and sand in Tehran. $PM_{2.5}$ from "natural" origins such as dust and sand contributes to about one-in-four particles in Tehran (see Figure 6). Prevailing winds from west of Tehran bring dust storms either from other areas near Tehran (including a desert near Tehran) or from even from neighboring countries. Tehran experienced high AQI in spring and summer of 2015 due to the dust storms and the AQI remained high until the end of

FIGURE 5. SOURCES OF PM POLLUTION IN TEHRAN
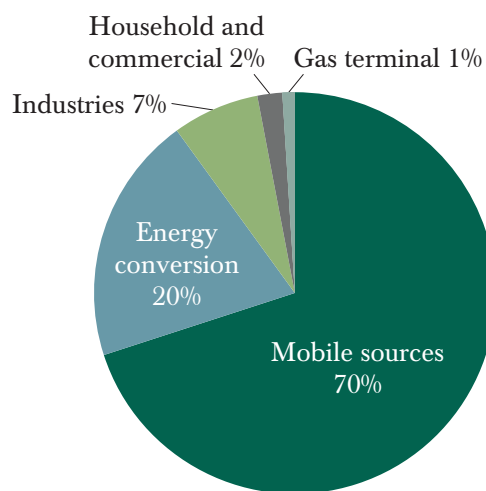
Source: Shabhazi et al. 2016b

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[12]Shabhazi et al. (2016) use emission inventories to disentangle the sources. Conducting source apportionment studies, analyzing particles by receptor models, using methods such as Positive Matric Factorization, which requires in depth modeling and a wealth of filter sample data, would deliver good insights into not only the share of each sector to the emissions, but also to ambient concentration levels. Arhami et al. (2017) provide the chemical speciation distinguishing between the contribution of several major mass constituents to $PM_{2.5}$ in Central Tehran. However, it is not straight forward to translate these constituents to the above mentioned sources (mobile, energy, industries, etc.). Due to the absence of a receptor model looking at these factors, we rely on the emission contributions instead.

the year.[13] The one-in-four dust share of particles for Tehran is a significant, but dust in Tehran is far less important than it is elsewhere in Iran, for example in the cities of Zabol, Ahvaz, and Bosher, where the preponderance of PM pollution originates from dust and sand.[14]

The contribution of each source varies substantially within a year. Arhami et al. (2017) provide a source identification study allowing us to distinguish between sand, dust, and anthropogenic sources. Organic matter, dust, and sulfur are the main components of $PM_{2.5}$ in Tehran. The contribution, or rather the explained variation of these components, varies in different seasons. In the summer, up to 56 percent of $PM_{2.5}$ is explained by dust, while in winter it can as low as 7 percent. In the winter, toxic metals are the main components of $PM_{2.5}$. Anthropogenic urban sources such as vehicles play a significant role in the production of $PM_{2.5}$.

There are challenges associated with combining the findings from the above-mentioned studies by Arhami et al. (2017) and Shabhazi et al. (2016) as they use different methods and data to arrive at their estimates. Researchers from the University of Southern California, notably Mohamad Sowlat, are currently in the process of finalizing a Positive Matrix Factorization (PMF) source attribution study for Tehran, which would improve on the two studies by assessing the relative contribution of different sectors, as well as natural sources. The authors have communicated some preliminary findings from this ongoing study, and they indicate that the results show slightly lower contributions of transport to the pollution, and also slightly lower contributions from natural dust. We synthesize that due to the small differences between the new PMF study and the results from Arhami et al. (2017) and Shabhazi et al. (2016) cited in this paper, our main narrative surrounding the priority sectors remains unchallenged.

FIGURE 6. CONTRIBUTIONS TO $PM_{2.5}$

Source: Arhami et al 2017

3.2 CARS ARE THE MOST ABUNDANT VEHICLES; HEAVY-DUTY VEHICLES ARE THE MOST POLLUTING

In this section, we classify vehicles into three categories: motorcycles, cars (which includes taxis, pick-ups, and passenger cars), and heavy-duty vehicles (HDVs).

Cars are the most abundant vehicle category. There are about 4.24 million vehicles in Tehran. Cars are the largest vehicle type, with a total fleet of 3.37 million, or 80 percent of all vehicles (see Figure 7). Of all cars, 90 percent are passenger cars, 8 percent are pick-

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[13]2016 Tehran Air Quality Control Report

[14]Zabol, a city to the east of Iran, is affected by relentless dust storms and the "120 days of wind" phenomenon. It is also close to the seasonal Lake Hamon, which is often dry. In this location, most PM particles originate from dust and sand. In Bosher, a city in the South-East of Iran, which lies in a vast plain with a desert climate, most of the PM pollution originates from dust and sand Similarly, in Ahvaz, a city in the South-East of Iran, much of the PM pollution originates from sand and dust and much of it is "blown in" from adjacent countries.

FIGURE 7. TYPE OF REGISTERED VEHICLES IN TEHRAN (2013–2014)

Heavy-duty vehicles 2%
Motorcycles 18%
Cars 80%
Taxis 2%
Pick-ups 8%
Passenger cars 90%
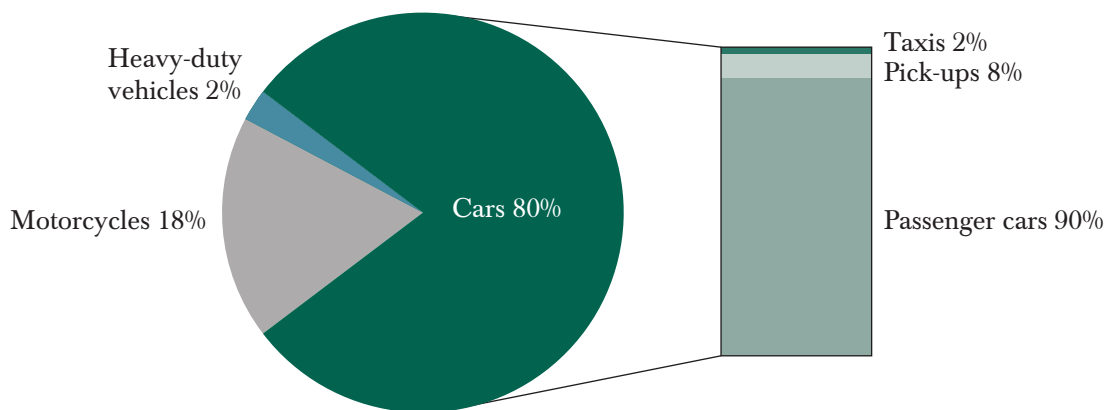
Source: Hosseini and Shabasi 2016

FIGURE 8. SOURCES OF MOBILE PM EMISSIONS

Cars 3%
Motorcycles 12%
Heavy-duty vehicles 85%
Private buses 35%
Municipal buses 28%
Trucks 28%
Minibuses 8%
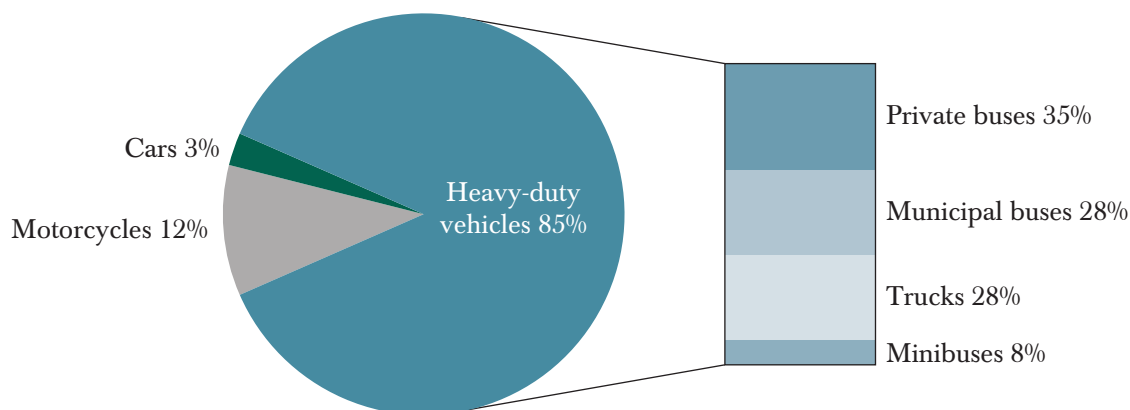
Source: Based on Shabhazi et al. 2016b

ups, and 2 percent are taxis (Hosseini and Shahbazi 2016). The second largest category, in terms of sheer numbers, are motorcycles, amounting to a total of 0.76 million, or 18 percent of total vehicles. The smallest category is HDVs[15], with a total of 0.1 million vehicles, or about 2 percent of total vehicles in the streets of Tehran.

Heavy-duty vehicles (HDVs) contribute the most to PM pollution. Even though cars are the most abundant and the most congestion-causing vehicle type on the streets of Tehran, they only contribute about 3 percent of the city's mobile PM pollution (see Figure 8). Similarly, despite motorcycles being the most pollution-intensive vehicle per passenger, they only contribute to about 12 percent of the total mobile PM emissions. In turn, HDVs contribute about 85 percent to mobile PM emissions. Amongst HDV vehicles, private sector buses (35 percent), followed by Tehran municipal buses (28 percent), and trucks (28 percent), contribute the largest

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[15]For simplicity, in the remainder of the paper we will refer only to heavy-duty vehicles, or HDVs. This reference includes both heavy and medium-duty vehicles.

shares to the pollution load (Shahbazi et al. 2016). HDVs mostly run on diesel, which has a much higher PM emissions factor than petroleum or natural gas. For example, in idle mode, compressed natural gas (CNG) buses emit 70 mg/hr., whereas diesel buses emit 27,030 mg/hr. (Shabhazi et al. 2016a).

3.3 HDVs ARE POLLUTING BECAUSE OF THEIR AGE AND OLD VEHICLE TECHNOLOGY

The age of Heavy-Duty Vehicles is to blame for their substantial contribution to PM air pollution. HDVs are the largest contributor to mobile PM sources not because of the size of the vehicle fleet, but mainly because of the age of the fleet. On average, 30 percent of HDVs are more than 20 years old, with almost 60 percent of minibuses being more than 20 years old (see Figure 9).

The outdated vehicle technology standards of HDVs are also to blame for their significant contribution to air pollution. Iran introduced Euro 1 standards in 2003, Euro 2 standards in 2005, and Euro 4 standards in 2014 (as a benchmark, European Union [EU] countries use Euro 6). Even though Euro 4 was introduced, the HDV fleet in Tehran is still largely meeting Euro 3 standards or less. In fact, the majority of vehicles only meet the Euro 1 standard (see Figure 10). At Euro 3 standard and lower, there is no requirement for after-treatment technology in the exhaust. As such, all of Tehran's HDV diesel fleet consists of vehicle that have received no after-treatment technologies such as diesel particulate filters (DPF), selective catalytic reduction (SCR), and diesel oxidation catalyst (DOC).

In 2015, the government increased the emission standards for HDV diesel vehicles to Euro 4, including the use of DPF technology. Euro 4 requires engines to use diesel fuel containing less than 50 parts per million (ppm) of sulfur, which is not widely avail-

FIGURE 9. AGE OF THE TEHRAN FLEET
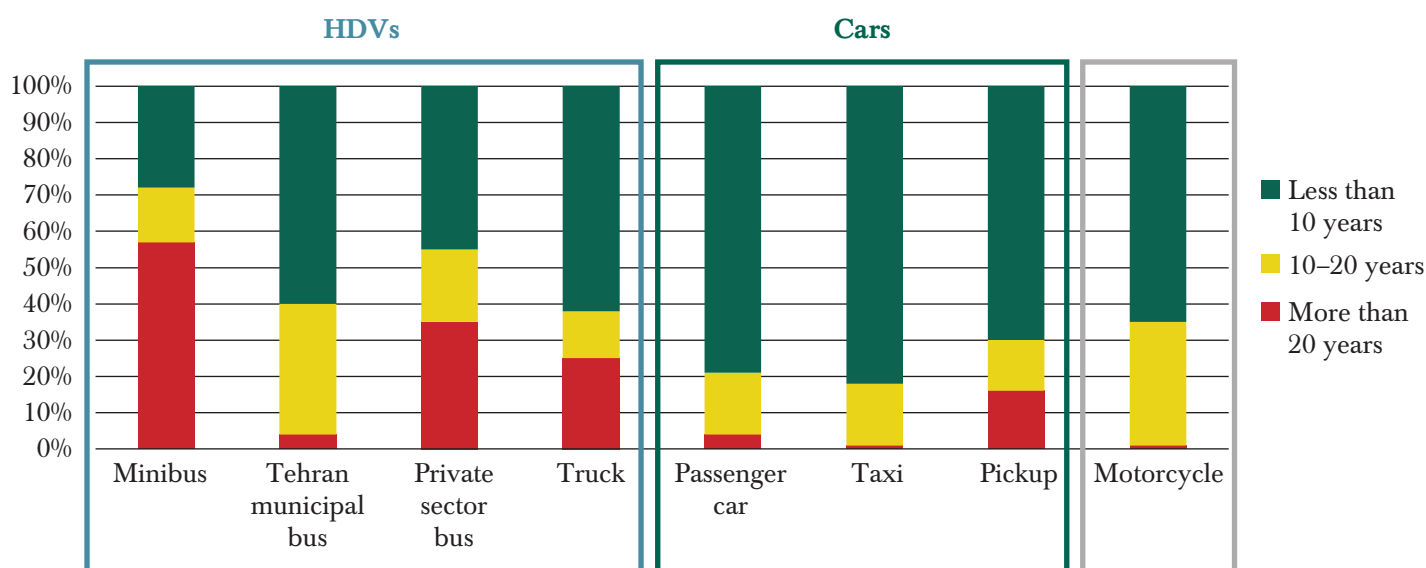
Source: Shahbazi et al. 2016b

FIGURE 10. VEHICLE STANDARDS FOR TEHRAN FLEET
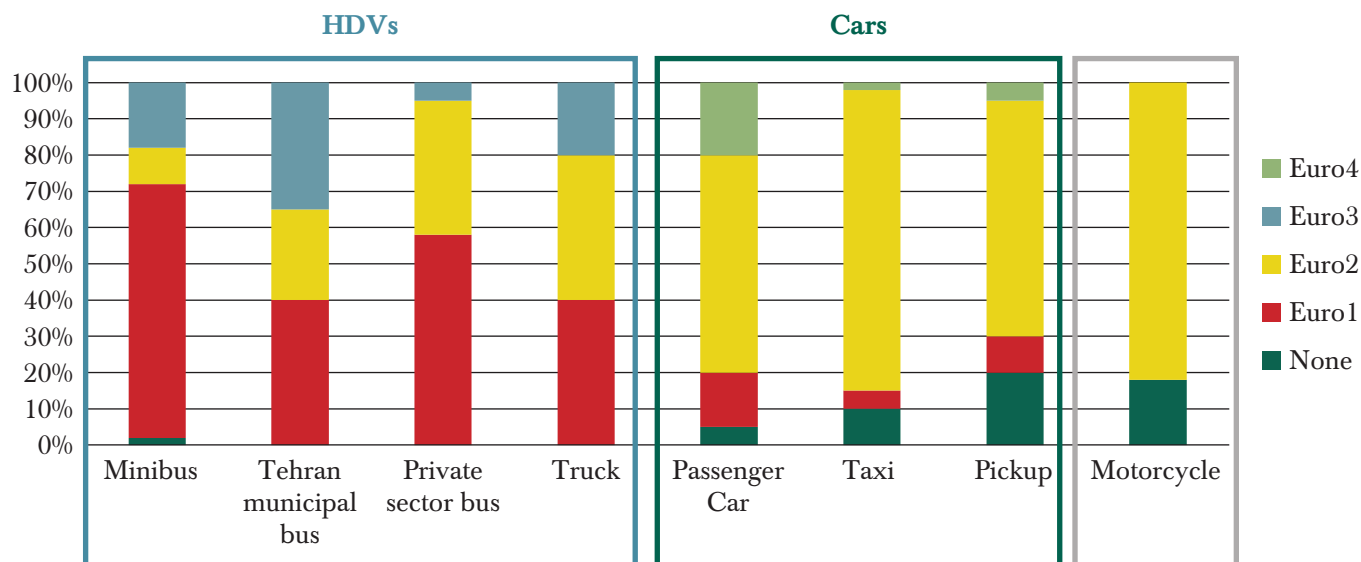
Source: Shahbazi et al. 2016

3.4 MOTORCYCLES ARE THE SECOND LARGEST CONTRIBUTOR TO PM IN TEHRAN

Motorcycles represent about 18 percent of total vehicle fleet in Tehran (as shown in Figure 7), amounting to about 1 million gasoline motorcycles (Hassani and Hosseini 2016). Motorcycles are the second largest contributor to PM, even before cars. As shown in Figure 8, motorcycles emit 12 percent of mobile particulate matter pollution emissions. One of the main reasons for their high contribution to emissions is that a large part of the fuel consumed in motorcycles burns incompletely. Thus, motorcycles contribute to primary PM through direct exhaust, and to secondary PM by producing unburned fuels (volatile organic compounds), which convert to PM under sunlight and in the presence of nitrogen oxides (NOx). The Tehran motorcycle fleet consists mostly of carburetor-equipped motorcycles,[16] which are typically less fuel efficient and emit more emissions compared to newer, fuel injection technology. A recent survey by Hassani and Hosseini (2016) indicates that about 40 percent of the fuel consumed by a 125cc motorcycle with a carburetor-equipped engine burns incompletely.

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[16]Old motorcycles with carburetor engines have higher emissions compared to new technology engines such as fuel injection systems. The main difference between a carburetor and a fuel injection system is the amount of air and gasoline that can get into the engine cylinders. The carburetor system cannot monitor the air-to-fuel ratio for each cylinder. Fuel injection systems can better adjust the release of air and the injection of fuel into the cylinder, conserving gasoline. Therefore, fuel injection systems have lower emissions and higher fuel efficiency.

3.5 CARS ARE THE THIRD CONTRIBUTOR TO PM IN TEHRAN

The technology of cars is old. In the context of this paper, cars include small pick-ups, passenger cars, and taxis. In Tehran, 22 percent of pick-ups, 9 percent of passenger cars, and 5 percent of taxis have carburetor engines, which produce significantly more emissions than the newer technological alternative, fuel injection, because they need more fuel and are less efficient in using a unit of fuel. While only 9 percent of passenger cars are carburetor-equipped, they contribute to 51 percent of total emission from passenger cars. If these vehicles were to be replaced with Euro 4 vehicles, emission levels would drop significantly (Shahbazi et al. 2016).

CHAPTER FOUR
A FRAMEWORK TO REDUCE AIR POLLUTION IN TEHRAN

Having established that the transport sector is the main contributor to air pollution in Tehran, in this section we provide a framework to reduce air pollution in the sector. First we present Iran's main achievements in reducing air pollution, in terms of regulations, policies, technologies and fiscal at both the broad transport level and at the vehicle level. Next, we discuss policy priorities for bringing about cleaner air in Tehran. While this paper focuses mainly on improving air quality, the identified policies have sizeable co-benefits such reduced congestion and travel time, fewer accidents, and increased economic productivity.

4.1 IRAN'S MAIN ACHIEVEMENTS IN REDUCING AIR POLLUTION

4.1.1 AN IMPROVED REGULATORY FRAMEWORK

Iran has put strong air-quality legislation in place:

» Iran passed its first National Clean Air Regulation in 1975. The country adopted its first Clean Air Act in 1995. The most updated version of the Clean Air Act was approved by Parliament in August 2017. The Clean Air Act is the highest level of legislation approved by the Parliament of Islamic Republic of Iran (IRI) and is empowered by the signature of the president.

» In 2012, to improve the age of the vehicle fleet, the Cabinet of Ministers issued legislation prohibiting the operation of vehicles of a certain age in eight Iranian cities, including Tehran. The age limit for HDVs is 20 years, for taxis it is 10 years, for public transit buses it is 8 years, and for private light duty vehicles 20 years. Although the legislation is in place, it is not fully enforced due to fear of social setbacks.

» In 2014, to improve vehicle technology, the Cabinet of Ministers issued legislation asking for DPF retrofitting of all public transit buses in large cities; installation of DPF on all new HDV diesel vehicles; replacement of catalysis on all taxis; replacement of gasoline motorcycles with electric ones; and requiring Volatile Organic Compound (VOC) collection system in all gas stations. Each

requirement has a deadline and an organization designated responsible for its implementation. However, as the legislation has limited supporting studies and no direct budget to support it, it has not yet been implemented.

» In 2016, the Cabinet of Ministers issued the most comprehensive legislation on air pollution in the country's history. The legislation introduced low emission zones (LEZs) in large cities by municipality; prohibited the production and import of carburetors gasoline motorcycles; further lowered the sulfur content of diesel fuel; encouraged the electrification of the fleet; and provides subsidies to encourage fuel efficient vehicle technologies and fleet renewal, among other important reforms. The legislation was accompanied by US$5.5 billion in low interest loans, subsidies for fleet renewal, and other financial incentives such as a reduction in import tax from 40 percent on all vehicles to 4 percent on efficient vehicles.

4.1.2 IMPROVED PUBLIC TRANSPORTATION

Improving public transportation can encourage people to shift from private passenger cars to public transportation options, reducing fuel consumption and emission by reducing passenger-kilometers. Below are some initiatives already taken by the government.

The public transport system in Tehran has substantially improved over the years:

» Tehran Metro consists of five operational metro lines. In 2010, an average of four million passengers a day used the metro network. It was calculated that the metro generated an average savings of 27 minutes per passenger per trip, reduced the consumption of benzene/gasoline by 334 million liters a year, and reduced carbon dioxide emissions by 900 tons per year.[17] As of 2017, the metro network is 192 km long, with another 62 km under construction.[18] The number of passenger trips has increased from 490 million in 2010 to 670 million in 2015.

» The first Bus Rapid Transit (BRT) line was introduced in 2008. In 2017, Tehran had seven BRT lines, which together have a total length of 100 km. The BRT system transports an estimated four million passengers every day. Three additional BRT lines are planned for an additional length of 67 km.[19]

Despite technology and funding limitations imposed by international sanctions, public transport has substantially increased over the past decades. Without a doubt, this has slowed down emissions even in the face of population growth and urbanization. Continuing to develop public transportation in Tehran the coming years is highly recommended. Increasing the capacity of existing lines, as well as possibly expanding the metro system to connect to smaller cities around Tehran, should be considered. Further expanding the metro system will further reduce emissions by passenger-kilometers travelled and improve air quality. Aside from physical improvements to the public transportation system, behavioral interventions targeted at incentivizing people to take public transportation rather than commuting by passenger car, are also important.

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[17]Statistics provided by: www.metro.tehran.ir
[18]For more information, visit: www.globalmasstransit.net
[19]For additional information, visit: www.en.tehran.ir

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4.1.3 ENCOURAGED ALTERNATIVE MODES OF TRANSPORT

Various cities have successfully encouraged non-motorized transport by building pedestrian and bicycle paths or by encouraging cleaner alternatives such as electric motorcycles.

Encouraging Electric Motorcycles. In Iran, the old, carburetor technology of much of the existing motorcycle fleet has contributed to high level of CO, VOC, and PM emissions (Shahbazi et al. 2016). Since 2014, the Municipality of Tehran has been promoting the use of electric motorcycles as an alternative to gas fueled motorcycles. Buyers receive a 25-million rial (USD $675) subsidy or no interest loans from the municipality. Yet demand for electric motorcycles remains low. Their cost is two to three times that of a conventional gasoline motorcycle, and uptake by the public is slow. The recently implemented ban on carburetor-equipped motorcycles (September 2016) is likely to have a positive impact on the demand for electric motorcycles in the long run.

Challenge with Cycling. Tehran is located on the hills of the Alborz Mountains. The altitude difference in the city from north to south is in the order of 500 meters. The slope imposes some drawbacks for cycling. There are currently very few safe cycling paths in Tehran. Creating safe cycling paths, especially to and from public transit hubs, could yield substantial benefits. However, the design of such a system needs to consider the geography of the city as well as the cultural challenge facing female cyclists. Allowing bicycles on the metro, or putting bike racks on buses, would allow people to combine cycling with public transport and be yet another incentive promoting cycling.

4.1.4 IMPROVED TRAFFIC MANAGEMENT

Improving traffic management leads to reduced congestion, better mobility and reduced emissions. The Municipality of Tehran has undertaken several initiatives to improve traffic management. Notably:

» In 2005, the Tehran Traffic Control Company, a subsidiary of the Municipality of Tehran, started the odd-even scheme in the central zone of Tehran to control the volume of traffic. Public transportation improvements (bus and metro) were done in parallel to this plan.[20] The objective was to restrict the number of passenger cars in the central zone of Tehran to 80,000 at a time, without restricting taxis and motorcycles. The odd-even scheme started as a temporary measure during high pollution episodes in the winter. However, it remained in place and was enforced by traffic cameras at the border of the odd-even zone in city center. While the initiative was successful in limiting congestion, it had mixed success in reducing air pollution as motorcycles and taxis, which are important emitters, were not restricted; and scanning license plate numbers is not relevant to pollution.

» The low emission zone (LEZ) introduced in 2016 aims at restricting emission levels instead of license plate numbers. Under this scheme, the LEZ is equipped with cameras to scan vehicles' license plates. Cars that have not undergone

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[20]For more information, please visit: http://trafficcontrol.tehran.ir/default.aspx?tabid=108&ArticleId=715

mandatory, annual quality inspections are fined. Currently, both the odd-even scheme and LEZ are imposed on the same area (Shabazi et al. 2017). The LEZ plan is certainly more efficient in terms reducing air pollution; however, its impact on reducing congestion remain to be seen. We recommend the expansion of the LEZ program, which currently charges in-use cars that have not been maintained and inspected, to also charge cars based on their vehicle technology standards and emission levels, which are already classified in the maintenance process, such that it becomes a "real" LEZ scheme. Moreover, the inclusion of motorcycles in the scheme should be pondered, particularly because they are far worse polluters than cars.

4.1.5 IMPROVED FUEL QUALITY

Emissions can also be reduced by improving fuel quality and vehicle technology. It is important to treat fuels and vehicles as a joint system, since cleaner vehicle technology generally requires improved fuel quality (World Bank 2004). Having taken major measures to improve its fuel quality, future reforms should focus on improving vehicle technology.

The IRI has made substantial progress in improving the quality of its fuel (both gasoline and diesel) by eliminating lead, reducing sulfur and benzene content. Steps include:

» **Elimination of lead.** Historically, to enhance the production of gasoline in Iran, lead, benzene, aromatics, oxygenated octane enhancer, and other additives were used. The lead additive was removed in 2002. However, benzene, aromatic, and oxygenated octane enhancers such as methyl tert-butyl ether, which is harmful to the environment, were still used in gasoline production. Benzene in gasoline and diesel was about 2.9 percent by volume, which is higher than the national standard of less than 1 percent by volume (Hosseini and Shahbazi 2016). From 2013, The National Iranian Oil Refining and Distribution Company started to improve the quality of gasoline and diesel fuels with positive results. In 2015, the AQCC indicated that the benzene content of fuel had decreased to below 1 percent by volume.
» **Reduction of sulfur.** The sulfur content of gasoline distributed in Tehran was reduced from 200 ppm in 2014 to about 20 ppm in 2017. The sulfur content of diesel fuel distributed in Tehran was also reduced from around 7000 ppm in 2014 to less than 50 ppm (AQCC 2015).
» **Natural gas.** As indicated below, the use of natural gas in vehicles has increased substantially in Tehran.

4.1.6 REDUCED FUEL SUBSIDIES

In 2010, the IRI launched an ambitious energy subsidy reform program, along with a parallel cash transfer program to moderate the impact on households. The price of gasoline at the pump increased from $0.1 per liter in 2010 to $0.37 in 2014[21] as a direct consequence. Historically, low fuel price in Iran created little incentive for fuel conservation; reducing fuel subsidies, which of course also has other positive welfare

consequences, has positive effects on air pollution. Increasing gasoline prices, encourage a more frugal use of the resource, and reducing vehicle-kilometers travelled is expected to have positive consequences for air quality. The slashing of fuel subsidies and the consequently higher fuel prices provide incentives to switch from private to public transportation and non-motorized means of transportation.

4.1.7 IMPROVED VEHICLE EFFICIENCY

Vehicle technology improvements, including emission control such as catalytic converters and exhaust gas recirculation, are driven to a large extent by emission standards (World Bank 2004). Moreover, measures to improve vehicle efficiency can only be fully efficient when accompanied by a good inspection and maintenance program. To improve its aging vehicle fleet (buses and cars), the IRI has taken the following measures:

» In 2005, the production of Iran's most popular car, the Paykan—which at one point was driven by almost 40 percent of Iranians—came to an end, partly because it was a heavy polluting vehicle. This decision led to a decrease in the number of unhealthy days.[22]

» Since 2016, the use of DPF became mandatory for new vehicles (Hosseini and Shahbazi 2016). Yet there remain challenges with respect to compliance and enforcement.

» **Natural gas vehicles.** The IRI has the largest number of natural gas vehicles in the world, with an estimated three million vehicles, or 20 percent of its total vehicle fleet.[23] These are vehicles that use either compressed natural gas (CNG) or liquefied natural gas (LNG).

» **Motorcycle technology upgrade.** A ban on licensing new carburetor-equipped motorcycles was put in place in September 2016, encouraging the production and import of fuel-injected or electric motorcycles. The gradual phasing out of polluting, carburetor-equipped motorcycles will take time, but in the long run this ban will yield positive impact of air quality. The government needs to make sure that all models of fuel-injected motorcycles comply with Euro 3 standards.

» **Provide financial incentives for hybrid and electric vehicles.** Recently, the government decreased the import tax from 40 percent to 4 percent for fuel-efficient vehicles. This low import duty contrasts quite starkly to the 55 percent tax still applied to cars with combustion engines. In fact, the low import duty level for hybrid and electric cars has resulted in a 112% increase in hybrid vehicle sales in 2015.[24] This is certainly a move in the right direction, but the price of fuel-efficient cars remains relatively high. Other incentive schemes such as exempting hybrid cars from parking fees and traffic congestion area fees could be used to promote the switch to cleaner transportation technologies.

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[21]As a reference in 2014 the average worldwide price of gasoline at the pump was $1.31 information provided by the German Agency for International Cooperation via https://data.worldbank.org/

[22]Please refer to: http://air.tehran.ir/ for more information اخبار-قدیمی-سوبسید-دولت-برای-خودروهای-هیبریدی-کجا-میرود

[23]Source: www.greencarreports.com/news/1093785_where-are-natural-gas-vehicles-most-popular-and-most-numerous

[24]*Source:* https://www.forbes.com/sites/sarwantsingh/2015/08/11/iran-automotive-industry-can-american-car-manufacturers-overcome-chinese-resistance/#7ba7483a556b

4.2 THE WAY FORWARD: POLICY PRIORITIES FOR TEHRAN

While we cannot recommend an optimal policy mix, as this would require additional evidence from cost-effectiveness and cost-benefit analyses, we can certainly narrow down all available options to a list of priority policies, and propose a ranking amongst them, given certain criteria. Out of all the policies we discussed in the previous section, we recommend a list of priority based on:

» feedback from air quality and transport experts knowing the Tehran context (see the list of experts in the acknowledgement section);

» meta-analyses of the successes of previous transport policies in comparable countries in curbing air pollution (see inter alia World Bank 2014; World Bank 2004; Shao et al. 2016; and Posada et al. 2015); and

» our own expertise from working on similar issues in similar countries.

The list of priority policies is presented in Table 2.

Moreover, we also recommend a certain sequence, emerging from the joint evaluation of selected decision-making criteria. The decision-making criteria include the timeframe, the financial cost that would be incurred by the government, and the effectiveness of implementing a certain measure to reduce air pollution concentrations. Naturally there are many other evaluation criteria for transportation policies, such as reducing congestion, reducing accidents, cost-recovery, or providing poorer areas with access to means of transportation. The effectiveness criterion we apply focuses solely on the potency of the evaluated policies to reduce air pollution. However, most policies discussed also come with these other benefits.

4.2.1 FIRST-ORDER PRIORITIES

Policies with short-term timeframes, low-to-medium financial costs, and high effectiveness can sensibly be regarded as first-order policy priorities. Based on our priority-setting exercise, we recommend four priorities:

» an HDV replacement program, including a scrappage component;
» a DPF retrofit program for HDVs;
» expansion of the LEZ; and
» an improved monitoring and enforcement system.

An HDV replacement program with scrappage. An HDV replacement program consists of providing financial incentives to owners of old vehicles to trade them in for new, less polluting, ones. The old fleet can either be displaced elsewhere, say to a less polluted area, which would help insofar as that it would reduce the local pollution in Tehran; or scrapped, which is preferable from national and global pollution standpoints.

Many countries have successfully used scrappage programs for HDVs and light duty vehicles (LDVs), including China's national and local scrappage programs, the United States' "Cash for Clunkers" and National Clean Diesel Campaign, Germany's Scrappage Bonus, Mexico's Federal Road Transportation Modernization Program, and Chile's

TABLE 2. TRANSPORT POLICY PRIORITIES FOR THE REDUCTION
OF AIR POLLUTION IN TEHRAN

Air Pollution Minimization Measures	Time-frame	Financial Cost	Effectiveness	Challenges
HDV replacement programs, including scrappage	Short-term	Low	High	Can create environmental damage if not managed properly (dismantling and recycling process); or simply displace pollution if not scrapped.
Diesel Particulate Filter (DPF) retrofit for HDV	Short-term	Low-Medium	High	Hard to select the appropriate technology. Need to provide the right financial incentive.
Low Emission Zone expansion (incl. pollution charges and motorcycles)	Short-term	Low	Medium	Need to study its impact on congestion, danger of perverse incentive, and disproportionate impact on the poor.
Inspection and maintenance	Short-term	Medium	Medium	Good system is in place for cars. Need to expand to light and heavy vehicles.
Incentivize electric and hybrid vehicles	Medium-term	Medium	High	
Incentivize non-motorized transportation	Medium-term	Low	Medium	
Expand BRT lines and possibly LRT lines	Medium-term	High	Medium	
Expand metro lines	Long-term	High	High	
Strengthening monitoring, measurement and analysis capacity	Medium-term	Low	Low	

Truck Swapping Program. Aside from tailoring the subsidies offered to the preferences and behaviors of drivers and companies in each of these countries, the introduction of complementary policies such as mandatory vehicle age limits and low emission zones has proven crucial for the success of these programs. Particularly in the case of Tehran, where most of the air pollution originates from older HDVs, such a government budget program could yield substantial reductions in pollution emissions. Targeting old HDVs is likely not only more effective but also more cost-efficient than the previous car scrappage program, which was scratched in November 2017. A more detailed analysis on the economics and fiscal impacts of an HDV replacement and scrappage program are highly recommended.

A comprehensive DPF program for HDVs. Both DPF new-fit and retrofit programs are important. For new-fit, it is mostly a compliance and enforcement issue since, as of 2016, new diesel vehicles in Iran must comply at least with Euro 4 plus DPF standards. Retrofitting should continue to be supported. We recommend that the program retrofitting of Tehran Public Municipal Buses with DPF technology, which recently passed the pilot stage in which a few dozen buses were retrofitted, be continued and supported. Several filter technology options were tested for their performance when used in the

Tehran context during the pilot stage. For example, they were evaluated against the city's fuel quality (e.g., not every pump meets the Euro IV 50ppm sulphur level) and its fleet quality. This provided detailed evidence as to what technology works best and under what conditions. This information is crucial in rolling out the next phases of the DPF HDV retrofit program. Aside from a continued implementation of the program, we also recommend its expansion to other HDV categories such as minibuses, private sector buses, and trucks.

Replace or repair? The joint implementation of HDV scrappage programs and HDV DPF retrofit programs is important. Depending on the emission levels, vehicle technology and age, and cost-effectiveness criteria, some vehicles should be repaired, while others should be scrapped. Retrofitting programs are usually sensible for "high-usage, high-emission urban vehicles that still have a significant economic life in the absence of the incentive" (World Bank 2004). On the other hand, a simple rule of thumb suggests that if the cost of repairing a vehicle exceeds the market value of that vehicle, it may be more sensible to scrap the vehicle (World Bank 2004). The success of any replacement scheme and DPF program is an improved inspection and maintenance scheme.

Expand low emission zones. In addition to repair and replacement programs, an expansion of the low emission zone (LEZ) to include motorcycles and the charging of pollution fees is a top policy priority. Expanding the LEZ scheme to include pollution charges, such that vehicles are charged depending on their age and emission technology, on top of charging those that were not regularly maintained—as initially pondered by its architects—is highly recommended. The necessary classification of pollution levels of vehicles (e.g., green sticker for low polluting, yellow sticker for moderately polluting, and red sticker for high polluting vehicles) is already in place. Regular monitoring and inspection is crucial for effectiveness. Expanding the LEZ system such that it also includes maintenance and pollution charging for motorcycles is also highly recommended. The current ban on large groups of cars in the central zone of Tehran (a subarea of the entire LEZ area) has led to the perverse outcome that it is teeming with motorcycles, which on average have an even worse pollution footprint. Therefore, we highly recommend that motorcycles are also part of the LEZ system of the future. The pollution charging LEZ scheme could work similarly to the one originally planned, but yet to be implemented, for cars, which is that greener vehicles pay less relative to "browner" vehicles, with cost exemptions for electric vehicles.

Improve monitoring and inspection. Like many countries, Iran adopted emission standards for stationary and mobile sources from the European Union. While proper emission standards are important, it is also important to have a strong inspection and certification process to ensure that standards are being followed. Iran has already invested in multiple vehicle inspection stations that issue periodic technical inspection (PTI) documentation. Recent changes aim to centralize PTI documentation and put the system under the jurisdiction of the Ministry of Interior. With this change, getting vehicle inspection data is made simpler, and vehicles without valid, annual PTI certification are being fined when entering the LEZ of Tehran. Further strengthening of PTI centers (in software, hardware, and technical training of personnel) for both light and heavy-duty vehicles will be very beneficial.

4.2.2 SECOND-ORDER PRIORITIES

Aside from the four policy priorities already discussed, four additional policies made it onto the priority list. They include:

» incentivizing electric and hybrid vehicles, including HDVs, cars and motorcycles;

» incentivizing non-motorized transport such as walking or cycling;

» expanding Bus-Raid Transport (BRT) lines and possibly converting currently busy BRT lines to Light Rail Transport (LRT) lines; and

» expanding metro lines.

These four transport policies made it only onto the second-order priority list because, while they have high expected effectiveness in reducing air pollution, they are currently quite costly and take a long time to implement.

Finally, strengthening the capacity to collect air quality data and to perform analyses (e.g., on sources or impacts of air pollution) that will inform decision-making and lead to evidence based policy-making, is a priority. This will require strengthening areas such as operating and maintaining monitoring stations, and collecting and analyzing data from filter samples. Improving on current emissions inventories and source apportionment studies, as well as mapping the spatial distribution of pollutants, is key in creating the knowledge base for policy making. These third-order priorities (as we termed them) on strengthening the data and analytics on air pollution are important as they underpin effective implementation of the first-order and second-order priority policies.

While each of the policy options suggested in the Table 2 would reduce air pollution and have other positive welfare effects, more work to determine the optimal policy mix, based for example on cost-effectiveness and cost-benefit criteria, is highly recommended. An example of such analysis includes a recent World Bank analysis for cost-benefit assessments of transportation measures in Pakistan (Sanchez-Triana et al. 2015). Among other measures, PM control technologies for in-use vehicles, such as DPF and DOC technologies, were evaluated in terms of their unit costs and benefits for health. The assessment quantified the health benefits from retrofitting HDVs (by way of reducing the negative health consequences from air pollution only) to range from about USD 300 to USD 1300 depending on kilometers travelled and the type of vehicle. These monetized benefits, from quantifying health improvements alone, were already roughly on par with the cost of the DOC technology; in fact, they were smaller than the cost of DPF technologies in the case of Pakistan.

4.3 CONCLUDING REMARKS

The government has managed to reduce air pollution in Tehran in recent years. A multitude of policy measures are responsible for air quality improvements, including:

» adopting higher fuel quality standards (Euro 4);

» improving traffic management to reduce congestion in the downtown area;

» achieving the largest natural gas vehicle fleet in the world;

» improving public transportation (BRT and metro); and

» slashing fuel subsidies.

The number of unhealthy days decreased by about half, from 216 days in 2011 to 111 days in 2015, avoiding premature deaths, morbidity and productivity losses, and ultimately saved Tehran's economy roughly half a billion USD per annum.

Moving forward, the government and the municipality of Tehran may choose to take further measures towards reducing air pollution. Certain measures, including:

  » replacement and scrappage programs for older HDVs;
  » a comprehensive DPF retrofit program;
  » improvement of vehicle monitoring and inspection; and
  » ensuring enforcement and compliance with latest fuel standards

are high on the list of policies that will do the job effectively and efficiently. Moreover, the expansion of the LEZs to charge vehicles based on vehicle technology and emission standards, and to include motorcycles, would be another important step in the right direction. Finally, investing more in the expansion of the public transportation system should bring Tehran closer to clean air.

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