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Source Apportionment, Identification and Characterization, and Emission Inventory of Ambient Particulate Matter in 22 Eastern Mediterranean Region Countries: A Systematic Review and Recommendations for Good Practice★

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★ This study is a part of a consultancy to provide a background assessment of air quality (AQ) management system for the Eastern Mediterranean countries in order to improve their capabilities to use the updated World Health Organization Air Quality Guidelines in compiling national AQ standards.

Abstract

Little is known about the main sources of ambient particulate matter (PM) in the 22 Eastern Mediterranean Region (EMR) countries. We designed this study to systematically review all published and unpublished source apportionment (SA), identification and characterization studies as well as emission inventories in the EMR. Of 440 articles identified, 82 (11 emission inventory ones) met our inclusion criteria for final analyses. Of 22 EMR countries, Iran with 30 articles had the highest number of studies on source specific PM followed by Pakistan (n = 15 articles) and Saudi Arabia (n = 8 papers). By contrast, there were no studies in Afghanistan, Bahrain, Djibouti, Libya, Somalia, Sudan, Syria, Tunisia, United Arab Emirates and Yemen. Approximately 72% of studies (51) were published within a span of 2015-2021. 48 studies identified the sources of $PM_{2.5}$ and its constituents. Positive matrix factorization (PMF), principal component analysis (PCA) and chemical mass balance (CMB) were the most common approaches to identify the source contributions of ambient PM. Both secondary aerosols and dust, with 12-51% and 8-80% (33% and 30% for all EMR countries, on average) had the greatest contributions in ambient $PM_{2.5}$. The remaining sources for ambient $PM_{2.5}$, including mixed sources (traffic, industry and residential (TIR)), traffic, industries, biomass burning, and sea salt were in the range of approximately 4-69%, 4-49%, 1-53%, 7-25% and 3-29%, respectively. For PM_{10}, the most dominant source was dust with 7-95% (49% for all EMR countries, on average). The limited number of SA studies in the EMR countries (one study per approximately 9.6 million people) in comparison to Europe and North America (1 study per 4.3 and 2.1 million people respectively) can be augmented by future studies that will provide a better understanding of emission sources in the urban environment.

Keywords: Source apportionment; Particulate matter; $PM_{2.5}$; PM_{10}; Eastern Mediterranean Region

1. Introduction

Long- and short-term exposures to ambient PM and its constituents are recognized as one of the most pressing topics in modern-day public health (Brook et al. 2017; Faridi et al. 2017; Lelieveld et al. 2015). Ambient PM is globally pervasive and is emitted from a number of sources, such as vehicular emissions, industrial units, power generation, agricultural burning, wildfires, resuspended dust and dust storm events (Goudie 2014; Hadley et al. 2018a; Hadley et al. 2018b; Querol et al. 2019). Source apportionment (SA) studies have become increasingly conducted to determine the origins of ambient PM, particularly $PM_{2.5}$ and its constituents (Hopke et al. 2020; Karagulian et al. 2015; Münzel et al. 2021). Identification and quantitative apportionment of ambient PM and its components (e.g., carbon species, sulfates, nitrates, metal (loid)s, and unknown constituents) to their sources is an important step in providing information that guides the development of air quality management strategies (Hopke et al. 2020; Karagulian et al. 2015; Münzel et al. 2021; Taghvaee et al. 2018a). Additionally, source specific PM concentrations are also being applied in health impact studies to be able to focus attention on those sources most likely to be responsible for the observed adverse health effects (Hopke et al. 2020; Karagulian et al. 2015; Münzel et al. 2021). Based on the undeniable importance of SA studies in designing mitigation strategies to improve ambient air quality and its beneficial health consequences, the World Health Organization (WHO) released its initial compilation of SA studies in 2015. This initial database was constructed by Karagulian and colleagues and has been published by the Atmospheric Environment journal in 2015 (Hopke et al. 2020; Karagulian et al. 2015; Münzel et al. 2021). Moreover, the other review on SA for both PM_{10} and $PM_{2.5}$ at global scale has been more recently conducted by Hopke et al. in 2020 (Hopke et al. 2020). In regional studies, Singh et al. (2016) have quantitatively investigated the source contributions of ambient $PM_{2.5}$ and PM_{10} in South Asia (Almeida et al. 2020; Singh et al. 2017). As a well-known multivariate receptor model, PMF has been widely applied for SA of PM mass concentrations and its composition around the world (Soleimanian et al. 2019; Taghvaee et al. 2018a; Taghvaee et al. 2018b). Other receptor models, including CMB and PCA, and also emission inventory approaches have been extensively used for identifying sources of PM (Arhami et al. 2017; Esmaeilirad et al. 2020; Shahbazi et al. 2016a). These models/approaches can link the ambient

PM mass concentration and its constituents to a number of sources such as traffic related emissions, secondary aerosols, industrial emissions, ship emissions, soil, road dust, biomass burning, sea salt, to name but a few (Taghvaee et al. 2018b). Consequently, the findings provided by the aforementioned models/approaches can be beneficial for authorities and policy-makers in each country or region in order to mitigate the leading contributor of ambient air pollution ($PM_{2.5}$) and its associated health impacts (Esmaeilirad et al. 2020; Taghvaee et al. 2018b).

The WHO reported that nearly 95% of the world's population lived in areas with ambient $PM_{2.5}$ concentrations exceeding the guideline (10 $\mu g\ m^{-3}$) recommended by the 2005 WHO health-based air-quality guidelines (Barn et al. 2018; Barzeghar et al. 2020; Brook et al. 2017; Rajagopalan et al. 2018). However, the updated WHO Air Quality Guideline that was recently published (September 2021) is much stricter (e.g., annual average guideline level for $PM_{2.5}$ is 5 $\mu g\ m^{-3}$ which is halved compared to previous value). Though ambient $PM_{2.5}$ levels are declining in many developed nations, the concentrations in the EMR countries remain unchanged or continue to increase because successful implementation of air pollution mitigation policies for the reduction of $PM_{2.5}$ exposures may be near impossible in these nations over a short- and even long-time periods (Barn et al. 2018; Bennett et al. 2019; Brook et al. 2017; Faridi et al. 2020; Hadley et al. 2018b). As a result, the majority of the $PM_{2.5}$-related health and economic impacts will occur in these countries (Barzeghar et al. 2020; Faridi et al. 2020). The underlying reasons for high level of ambient $PM_{2.5}$ concentrations across the EMR countries may be associated with dust storm events, unsustainable development, continuing urbanization and industrialization, increasing mobile sources and associated emissions alongside ineffective ambient air quality standards and ambient air pollution abatement policies at national and subnational levels (Amini et al. 2017; Amini et al. 2019; Danaei et al. 2019; Shahsavani et al. 2020; Shamsipour et al. 2019). Based on the aforementioned issues, we designed this study to systematically review all published and unpublished studies regarding the SA, identification and characterization of ambient PM as well as emission inventories for it in the 22 countries in the EMR and identify the most important sources for more effective air pollution control measures in this region.

2. Methods

2.1. Search strategy, Study inclusion criteria, Article selection and Data extraction

To identify the conducted studies (published and unpublished) concerning the SA, identification and characterization of PM in 22 EMR countries (**Figure S1**) as well as emission inventories, several approaches were used as follows: firstly, we conducted a systematic search of the articles based on the Preferred Reporting and Items for Systematic Review and Meta-Analysis (PRISMA) criteria (Faridi et al. 2021; Faridi et al. 2022), as shown in the **Figure S2a** and **b**. The search was performed on December 23, 2021. To access the relevant studies, we queried three English language databases, including Scopus, PubMed, and Web of Science Core Collection using the search keywords mentioned in **Table S1** and **S2** (Supplemental file). We had two inclusion criteria as follows: **1)** study methods: any types of SA (e.g., PMF, CMB, and PCA) and emission inventory approaches, and **2)** language: English. To identify and select the relevant papers, two authors (S.F (Sasan Faridi) and F.Y (Fatemeh Yousefian)) screened all articles, independently and in duplicate. We selected eligible articles based on the title and abstract, if they fulfilled both aforementioned inclusion criteria. Then, if the title and abstract of studies did not provide sufficient detail for a decision, two authors reviewed the full text of articles independently. To justify the exclusion of any article, a more rigorous second round of screening of all selected articles has been made by S.F. and F.Y, and any conflict and discrepancies between the preceding reviewers on the studies was resolved by M.S.H (Mohammad Sadegh Hassanvand) through verbal discussion and consensus. As another approach, to increase the sensitivity and gather the relevant records that may be unpublished, we have tried to identify them through health experts at the World Health Organization/ Regional office of the Eastern Mediterranean Regional Office/Regional Centre for Environmental Health Action (WHO/EMRO/CEHA). S.F and F.Y independently extracted the detailed information on the characteristics of studies, including study ID, country/city of the studies, the used approaches to identify sources, air pollutants and identified sources and their contributions (**Table 1** (for the studies of SA, identification and characterization of PM) and **Table S3** (for emission inventories)).

3. Results and Discussion

3.1. Overview of the included SA, identification and characterization studies

Table 1 provides a summary of SA, identification and characterization studies for PM in the EMR countries. As shown in the **Table 1**, detailed information on study ID, time interval of sampling, the used method for identifying SA of PM, the country and city of study and the apportioned air pollutants have been mentioned. Based on the information supplied in **Figure S2** and **Table S1**, of 333 articles identified, 71 met our inclusion criteria for final analyses. Amongst all 22 countries in the EMR countries, Iran with 30 articles had the highest number of studies on source specific PM followed by Pakistan (n = 15 articles) and Saudi Arabia (n = 8 papers), as shown in **Table 1**. Note that there were no studies in Afghanistan, Bahrain, Djibouti, Libya, Somalia, Sudan, Syria, Tunisia, United Arab Emirates and Yemen. Approximately 72% of all studies (51) were published within a span of 2015-2021 (**Figure S3**). **Figure S4** shows the pie chart of the number of papers with a given from the EMR countries with the listed particle metric. Almost 68% of published papers (48) have been performed to identify the sources of $PM_{2.5}$ and its constituents, including polycyclic aromatic hydrocarbons (PAHs), carbonaceous aerosols (like total organic carbon (OC), elemental carbon (EC) and black carbon (BC)) and heavy metals (**Figure 1**). In 12, 4 and 10 studies, the authors of published papers have identified the source contributions of PM_{10}, $PM_{10-2.5}$ and TSP. Interestingly, one study in Lebanon has determined the source contribution of PM_1 (**Figure S4**). Moreover, To specify the sources of ambient PM using different models and approaches mentioned above, the included studies have analyzed various chemical constituents (metals, water-soluble ion, PAHs, OC, EC, and BC), as presented in **Figure 1**. 34 studies have analyzed simultaneously two and more than two chemical constituents (metals + PAHs (two studies), (metals + BC (four studies), (metals + water soluble ions (six studies), water soluble ions + OC + EC (one study), metals + water soluble ions + BC (2 studies), metals + water soluble ions + OC + EC (10 studies) and metals + water soluble ions + PAHs + OC + EC (nine studies)) for specifying ambient PM air pollution sources. However, one group of chemical constituents (PAHs (19 studies) or metals (15 studies) or water-soluble ions (one study) or OC (one study)) has been analyzed specifying ambient PM air pollution sources. As presented in **Table 1**, the number of samples used to conduct models or approaches for specifying ambient PM sources in the countries of the EMR countries ranged from 12 to 1802 samples (153 for all studies, on average), though several studies have not reported the number of samples used. **Figure 2** gives the data on the number of studies with the application of different approaches. Given the used approaches, PMF, PCA and CMB were the most common approaches to identify the source contributions of PM because they were used in 39, 15 and 4 studies respectively.

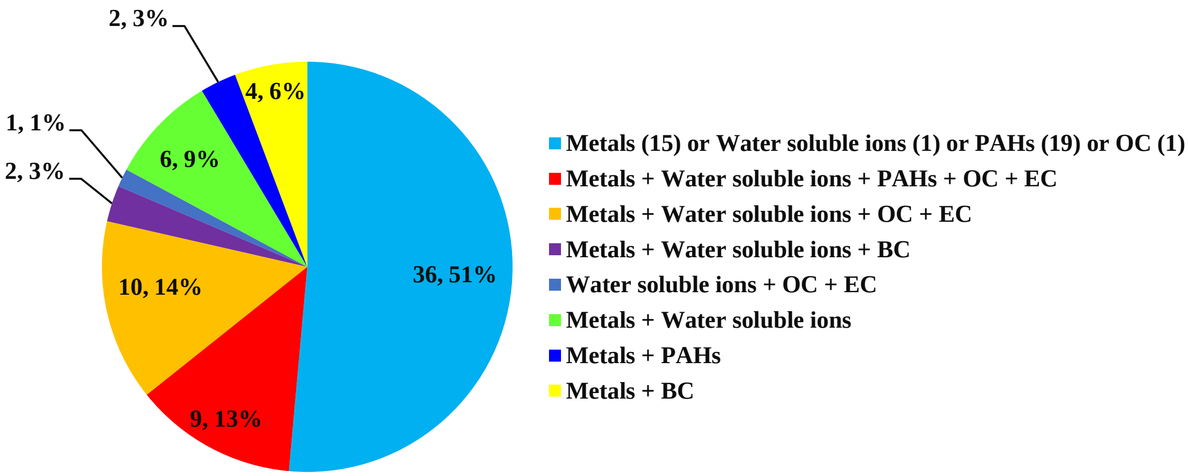


Figure 1. Analyzed various chemical constituents (the number and percentage of studies) to conduct SA models/ approaches (Considering simultaneously two and more than two chemical constituents for specifying ambient PM sources).

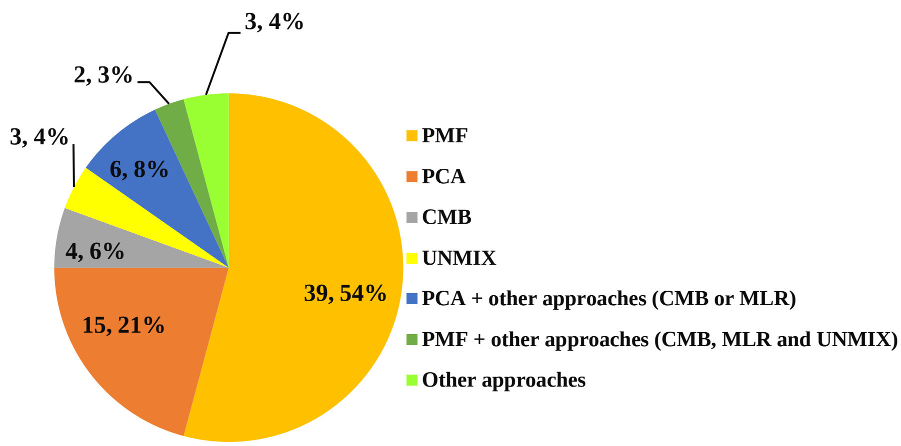


Figure 2. The number of studies with the application of different approaches for SA, identification and characterization of ambient PM in the EMR countries.

Table 1. Summary of SA, identification and characterization studies for PM air pollution in the EMR countries.

Study ID	Time interval	Site type of sampling	Method	Country/city	Air pollutants	# of samples
(Taghvaee et al. 2018a)	May 2012 to June 2013	Urban (residential)	PMF	**Iran**/ Tehran	$PM_{2.5}$-bound PAHs	74
(Altuwayjiri et al. 2021; Taghvaee et al. 2018b)	May 2012 to June 2013	Urban (residential)	PMF	**Iran**/ Tehran	$PM_{2.5}$	78
(Soleimanian et al. 2019)	May 2012 to June 2013	Urban (residential)	PMF	**Iran**/ Tehran	$PM_{10-2.5}$	60
(Esmaeilirad et al. 2020)	February 2014 to February 2015 and from late-January 2017 to mid-April 2017	Residential	PMF	**Iran**/ Tehran	$PM_{2.5}$	116
(Ali-Taleshi et al. 2021a; Ali-Taleshi et al. 2021b; Ali-Taleshi et al. 2021c)	March 2018 to February 2019	Urban	PMF	**Iran**/ Tehran	$PM_{2.5}$-bound PAHs	135
(Maleki et al. 2021)	March 2018 to March 2019	Urban (low, moderate and high traffic)	UNMIX model	**Iran**/ Tehran	$PM_{2.5}$-bound PAHs	60
(Shahsavani et al. 2017)	Every 3 days during the spring of 2015	Urban and Sub-urban	PCA	**Iran/** Shiraz	PM_{10}-bound PAHs	60
(Kermani et al. 2021b)	March 2018 to March 2019	Urban (residential)	PCA	**Iran**/ Karaj	$PM_{2.5}$-bound heavy metals	68
(Kermani et al. 2021a)	March 2018 to March 2019	Industrial area, High traffic areas; Middle and low traffic areas,	UNMIX model	**Iran**/ Tehran	$PM_{2.5}$-bound PAHs and heavy metals	108
(Gholampour et al. 2015)	January 2013 to September 2013	Sub-urban (Lake region)	PCA	**Iran/** Urmia	TSP and PM_{10}	48
(Akhbarizadeh et al. 2021)	During December 2016 and September 2017	Urban	PMF	**Iran/** Bushehr	$PM_{2.5}$-bound PAHs	46
(Eivazzadeh et al. 2021)	April 2017 to March 2018	Urban and Sub-urban	PCA	**Iran/** Tabriz	TSP	12
(Gholampour et al. 2016)	September 2012 to June 2013	Urban and Sub-urban (industrial)	PCA	**Iran/** Tabriz	TSP and PM_{10}	78

Study ID	Time interval	Site type of sampling	Method	Country/city	Air pollutants	# of samples
(Soleimani et al. 2018)	from March 2014 to March 2015	Urban and Industrial	PCA	**Iran/** Isfahan	$PM_{2.5}$-bound heavy metals	Not reported
(Sowlat et al. 2013)	April 2010 to March 2011	Urban	PMF	**Iran**/ Ahvaz	PM_{10}	72
(Sowlat et al. 2012)	April 2010 to March 2011	Urban	PMF	**Iran**/ Ahvaz	TSP	72
(Ashrafi et al. 2018)	Not reported	Urban (residential)	PMF, PMF-CMB, SPECIATE database-CMB	**Iran**/ Ahvaz	TSP	74
(Alidadi et al. 2021)	September 2018 to August 2019	City center-traffic, Near industrial zone, Far from urban traffic, Semi-traffic, Background	UNMIX model	**Iran**/ Ahvaz	PM_{10}	100
(Najmeddin and Keshavarzi 2019)	February 8 to March 9, 2017	Urban (residential), Highway and Industrial	PMF	**Iran**/ Ahvaz	PM_{10}	30
(Kholdebarin et al. 2015)	9 months (from 30/07/2012 up to 21/04/2013)	Urban (residential), Traffic zone and Industrial	CMB	**Iran**/ Tehran	PM_{10}	32
(Halek et al. 2010)	April 2004 to March 2005	Urban	Diagnostic ratios and PCA	**Iran**/ Tehran	PAHs (particulate and gaseous phases)	Not reported
(Azimi-Yancheshmeh et al. 2021)	Feb. 2018 to Jan. 2019	Urban (residential), Highway and Industrial	PMF	**Iran**/ Karaj	$PM_{2.5}$-bound PAHs	130
(Moeinaddini et al. 2014)	October 2011 to March 2012	Traffic zone (Between two highways)	PMF	**Iran**/ Tehran	Respirable particles-bound PAHs (PM_4-bound PAHs), Respirable particles-bound n-alkanes (PM_4-bound n-alkanes)	155
(Soleimani et al. 2021)	December 2017 to September 2018	Urban and Industrial	PMF	**Iran**/ Isfahan	$PM_{2.5}$-bound PAHs	200
(Abbasi et al. 2020)	August 6th to 31st, 2017 and January 28th to February 6th, 2018	Urban and Industrial	PMF	**Iran/** Asaluyeh	PM_{10}	48

Study ID	Time interval	Site type of sampling	Method	Country/city	Air pollutants	# of samples
(Arhami et al. 2018)	February 2014 to February 2015	Residential	CMB	**Iran**/ Tehran	$PM_{2.5}$ and Carbonaceous compounds (organic and elemental)	51
(Arhami et al. 2017)	February 2014 to February 2015	Residential	PCA-CMB	**Iran**/ Tehran	$PM_{2.5}$	51
(Altuwayjiri et al. 2022)	December 2019–March 2020 and May 2020–August 2020	Urban (residential)	PCA-MLR	**Saudi Arabia/** Riyadh	Oxidative potential of PM_{10}	Not reported
(Nayebare et al. 2018)	February 26, 2014 – January 27, 2015	Urban (residential) and Semi-industrial	PMF	**Saudi Arabia**/ Makkah	$PM_{2.5}$	40
(Khodeir et al. 2012)	Between June and September, 2011	Urban (residential and new residential) and Sub-urban	SPlus Factor Analysis model with Varimax rotations	**Saudi Arabia**/ Jeddah	$PM_{2.5}$ and PM_{10}	84 for $PM_{2.5}$ and 80 for PM_{10}
(Nayebare et al. 2016)	May 6th – June 17th 2013	Urban (residential) and Semi-industrial	PMF	**Saudi Arabia**/ Rabigh	$PM_{2.5}$	40
(Bian et al. 2016)	September 2011 to September 2012	Urban (residential) and Industrial	PMF	**Saudi Arabia**/ Riyadh city	PM_{10}	167
(Cusack et al. 2020)	September 2015 and December 2017	Semi-urban and Industrial	PMF	**Saudi Arabia**/ Jeddah	TSP	238
(Alghamdi et al. 2015)	Between 23 February 2013 and 23 April 2013	Urban (residential and background) and Industrial	PMF	**Saudi Arabia/** Jeddah	PAHs (particulate and gaseous phases)	180
(Shaltout et al. 2017)	December 2012 to January 2014	Urban	PMF	**Saudi Arabia/** Makkah	$PM_{2.5}$	Not reported
(Lurie et al. 2019)	August 2008 through August 2009	Urban (residential and commercial) and Industrial	PMF	**Pakistan/** Karachi	$PM_{2.5}$	377
(Harrison et al. 1997)	A period of 12 months (10/92 to 10/93)	Urban	PCA-MLR	**Pakistan/** Lahore	TSP and PM_{10}	62
(Mehmood et al. 2020)	Four seasons in 2017	Urban	PCA-MLR	**Pakistan/** Islamabad	$PM_{2.5}$-bound PAHs and PM_{10}-bound PAHs	160
(Lodhi et al. 2009)	November 2005 to March 2006	Urban (residential)	PMF	**Pakistan/** Lahore	$PM_{2.5}$	310

Study ID	Time interval	Site type of sampling	Method	Country/city	Air pollutants	# of samples
(Shaheen et al. 2005)	From October 2002 to May 2003	Urban	PCA	**Pakistan**/ Islamabad	TSP	134
(Shah et al. 2012)	September 2008–March 2009	Urban	PCA	**Pakistan**/ Islamabad	TSP	153
(Mansha et al. 2012)	January 2006 to January 2008	Urban (residential)	PMF	**Pakistan/** Karachi	$PM_{2.5}$	402
(Ishtiaq et al. 2021)	Summer in 2014	Urban	PCA-MLR	**Pakistan** (Karachi, Lahore, Faisalabad, Rawalpindi, Multan, Quetta, Peshawar and Gilgit)	PAHs (particulate ($PM_{2.5}$) and gaseous phases)	Not reported
(Alvi et al. 2020)	September 2015 to December 2016	Urban	PCA	**Pakistan/** Faisalabad	PM_{10}	117
(Raja et al. 2010)	November 2005 to January 2006	Urban	PMF	**Pakistan**/ Lahore	$PM_{2.5}$	129
(Ahmad et al. 2020)	July 2018	Urban	PCA	**Pakistan**/ Lahore	$PM_{2.5}$	30
(Ahmad et al. 2021)	February 2019	Urban	PCA-MLR	**Pakistan** (Lahore and Peshawar)	$PM_{2.5}$	60
(Shahid et al. 2018)	March – April 2009	Urban	PMF	**Pakistan/** Karachi	PM_{10}	Not reported
(Hamid et al. 2018)	From 15th February to 22nd April 2014	Urban, Traffic and Industrial	PCA-MLR	**Pakistan** (Islamabad and Rawalpindi)	PAH	25
(Khanum et al. 2021)	February 2014 and March 2014	Urban	PCA	**Pakistan/** Lahore	PM_{10}	30
(Javed et al. 2019)	May to December 2015	Urban (residential and commercial) and Sub-urban	PMF	**Qatar**/ Doha	$PM_{2.5}$ and $PM_{10-2.5}$	278
(Javed and Guo 2021)	May to December 2015	Urban (residential and commercial)	PMF	**Qatar**/ Doha	$PM_{2.5}$ and $PM_{10-2.5}$	108 for each of air pollutants
(Heo et al. 2017)	January to December 2007	Urban (residential)	PMF	**Middle Eastern cities in Jordan (**Amman**,** Aqaba, and Rachma**),** and **Palestine (**East Jerusalem, and Hebron**)**	$PM_{2.5}$	580

Study ID	Time interval	Site type of sampling	Method	Country/city	Air pollutants	# of samples
(Heo et al. 2017)	January to December 2007	Urban (residential)	PMF	**Middle Eastern cities in Jordan (**Amman, Aqaba, and Rachma**), and Palestine (**East Jerusalem, and Hebron**)**	$PM_{2.5}$	580
(von Schneidemesser et al. 2010)	January to December 2007	Urban (residential and commercial)	PMF	**Middle Eastern cities in Jordan (**Amman and Rachma**) and Palestine (**East Jerusalem and Hebron**)**	$PM_{2.5}$-carbonaceous aerosols	120
(von Schneidemesser et al. 2010)	January to December 2007	Urban (residential and commercial)	PMF	**Middle Eastern cities in Jordan (**Amman and Rachma**) and Palestine (**East Jerusalem and Hebron**)**	$PM_{2.5}$-carbonaceous aerosols	120
(Hamad et al. 2015)	From September 2012 through September 2013	Urban (commercial)	CMB	**Iraq/** Baghdad	$PM_{2.5}$-carbonaceous aerosols	53
(Alahmad et al. 2021)	October 2017 to October 2019	Urban (residential)	PMF	**Kuwait** (Kuwait city and Ali Sabah Al-Salem)	$PM_{2.5}$	1186
(Al-Dabbous and Kumar 2015)	31 days during the summer months of May and June 2013	Urban	PMF	**Kuwait/** Fahaheel	Concentration of particles with 5 – 1000 nm	Not reported
(Waked et al. 2015)	July 2011	Sub-urban	Chemical-transport model (CTM)	**Lebanon/** Beirut	$PM_{2.5}$-Total organic carbon (OC)	20
(Jaafar et al. 2021)	November 2016 and November 2017	Urban (background)	PMF	**Lebanon/** Beirut	$PM_{2.5}$-bound PAHs	55
(Saliba et al. 2010)	Between 2003 and 2007	Urban (residential and commercial)	Mettler-Toledo microgram balance (model UMX2)	**Lebanon/** Beirut	$PM_{2.5}$ and PM_{10}	42 for $PM_{2.5}$ and 41 for PM_{10}
(Alolayan et al. 2013)	Between February 2004 and October 2005	Urban (residential)	PMF	**Kuwait/** Kuwait city	$PM_{2.5}$	1802
(Shaltout et al. 2020)	October 2010 to May 2011	Urban (residential) and Industrial	PCA	**Egypt/** Greater Cairo	$PM_{2.5}$	32
(Boman et al. 2013)	September 2010 and May 2011	Urban (residential)	PCA	**Egypt/** Central Cairo	$PM_{2.5}$	54

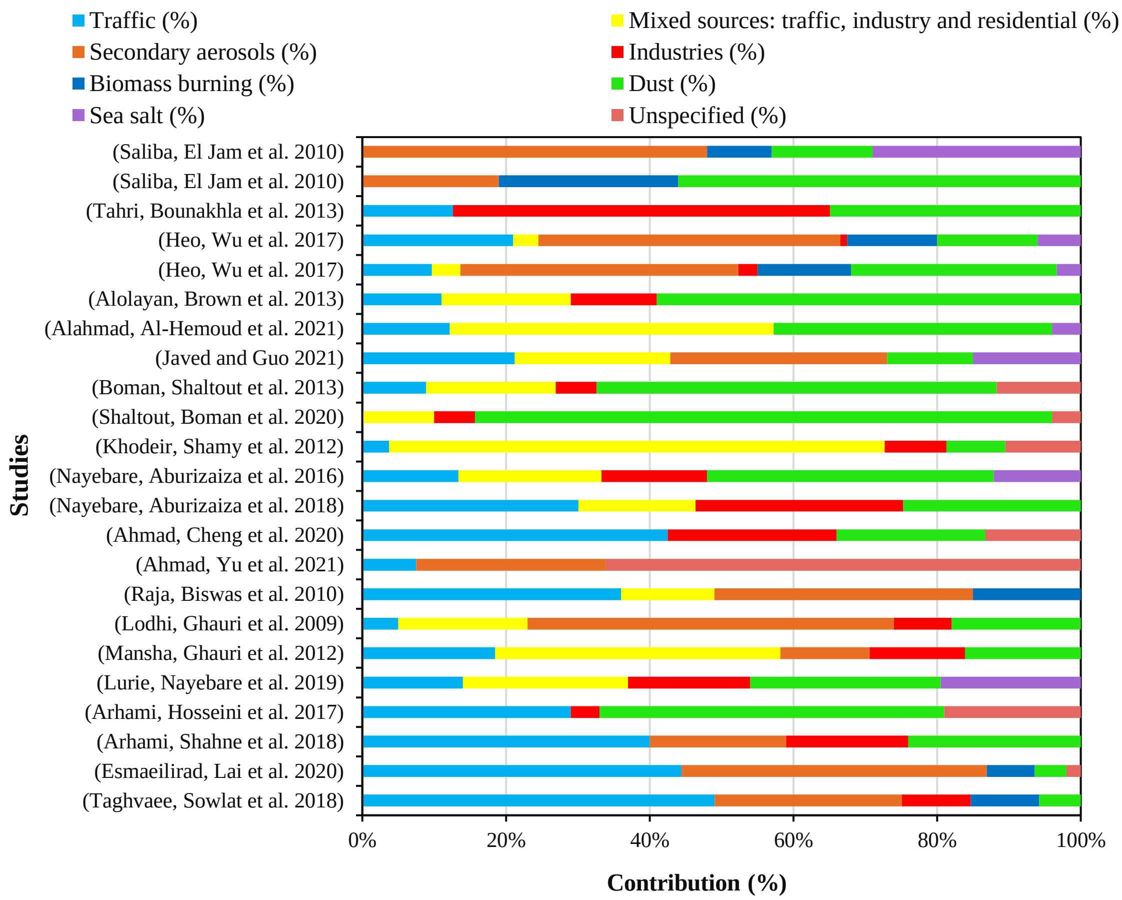
Study ID	Time interval	Site type of sampling	Method	Country/city	Air pollutants	# of samples
(Khairy and Lohmann 2013)	(July–August, 2010) and (December–January, 2011)	Urban (residential), Traffic and Industrial	FA/MLR, PMF and UNMIX	**Egypt/** Alexandria	PAHs (gaseous + particulate phases)	150
(Abu-Allaban et al. 2002; Abu-Allaban et al. 2007)	21 February–3 March and 29 October–27 November 1999	Urban (residential and background), Traffic, Industrial	CMB	**Egypt/** Cairo	$PM_{2.5}$ and PM_{10}	73
(Tahri et al. 2013)	February 2007 to February 2008	Traffic	PMF	**Morocco/** Kenitra city	$PM_{2.5}$ and $PM_{10-2.5}$	63 for each of air pollutants
(Abdul-Wahab 2004)	Not Reported	Urban (residential) and Industrial	PCA	**Oman/** Sohar	TSP-heavy metals	31

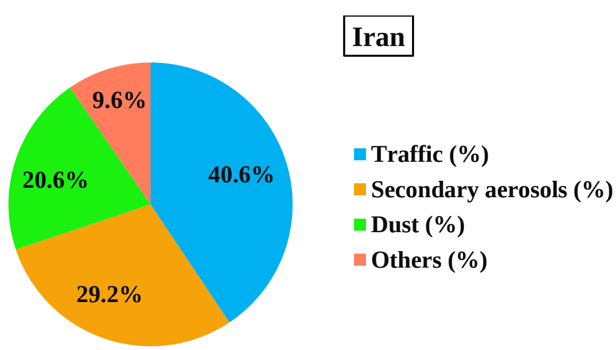
3.2. Source contributions to ambient $PM_{2.5}$ and PM_{10} in the EMR countries based on the SA, identification and characterization studies

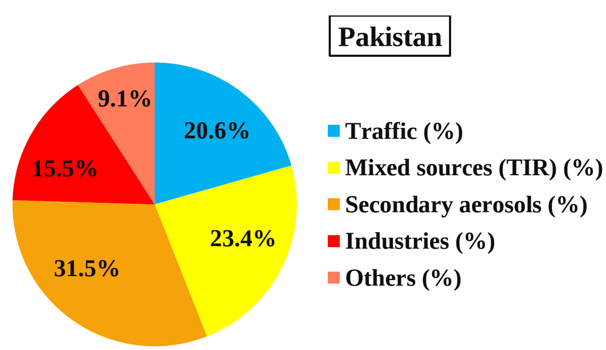
Figure 3 and **4** reveal the relative concentrations of sources to $PM_{2.5}$ and PM_{10} mass concentrations in the included studies. Included studies reported seven major sources for ambient $PM_{2.5}$ and PM_{10} including dust, traffic, industries, sea salt, biomass burning, and secondary aerosols. Since, some of them stated no specific sources for ambient $PM_{2.5}$ and PM_{10}, categorized into an unspecified category. As shown in **Figure 3**, both secondary aerosols and dust, with 12-51% (33% for all EMR countries, on average) and 8-80% (30% for all EMR countries, on average) made the greatest contributions to ambient $PM_{2.5}$ air pollution. The remaining sources for ambient $PM_{2.5}$ mass concentrations, including mixed sources (traffic, industry and residential(TIR)), traffic, industries, biomass burning, and sea salt were in the range of approximately 4-69%, 4-49%, 1-53%, 7-25% and 3-29%, respectively. Of the above-mentioned sources, dust had the greatest contribution to ambient $PM_{2.5}$ in Egypt (68%) and Kuwait (49%), while the figures for Saudi Arabia, Iran and Qatar were lower at 24%, 20% and 12%, respectively. In the studies conducted in Palestine, Jordan, Pakistan and Qatar, approximately 42%, 39%, 32% and 30% of ambient $PM_{2.5}$ mass concentrations were attributed to secondary aerosols, respectively. For the study performed in Morocco, nearly 53% of ambient $PM_{2.5}$ mass concentration was attributed to industries, whereas the figure for Jordan was lower at 3%. Traffic was the most dominant source for ambient $PM_{2.5}$ mass concentrations in Iran (41%), while it had the lowest contribution in $PM_{2.5}$ sources for Egypt (9%) and Jordan (10%). Biomass burning had nearly the same contribution in ambient $PM_{2.5}$ (13%) in the studies conducted in both Jordan and Palestine.

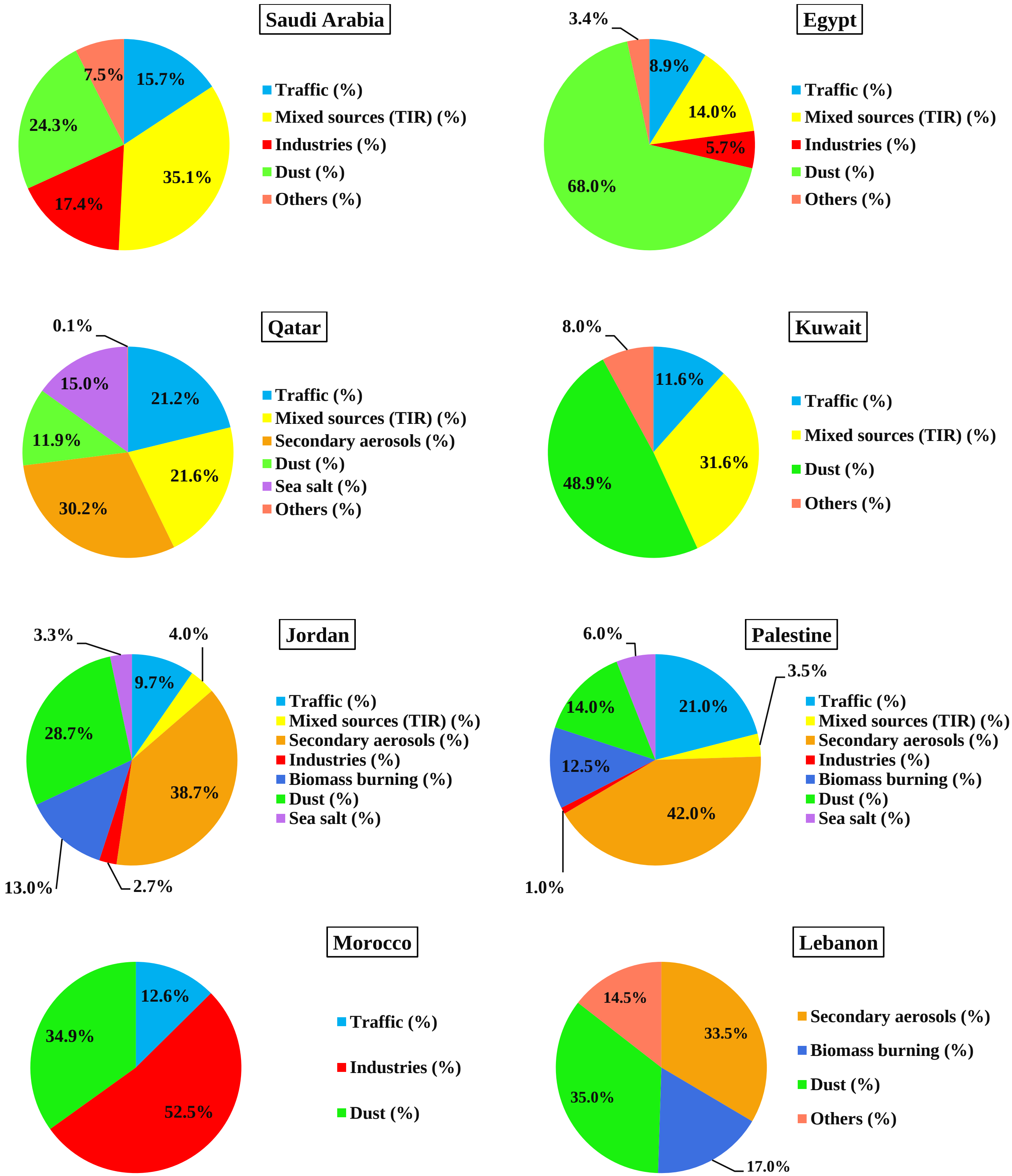
Regarding PM_{10} (**Figure 4**), the most dominant source of ambient PM_{10} mass concentrations was dust with 7-95% (49% for all EMR countries, on average), whereas the figure for secondary aerosols in these countries had the lowest contributions and ranged from 7-25% (18% on average). The contribution of mixed sources (traffic, industry and residential), sea salt, traffic, industry, and biomass burning were in the range of approximately 18-94%, 9-60%, 4-72%, <1-31% and 9-25%, respectively. In the studies performed in Iran, the most dominant source for ambient PM_{10} mass concentrations were sea salt and dust (26 % and

25%, on average). Given studies in Lebanon and Pakistan, the contribution of traffic for ambient PM_{10} mass concentrations (54% and 34%), was higher than that of in Iran and Saudi Arabia (21% and 11%). Comparing all EMR regions, industries made the highest concentributions to PM_{10} mass concentrations (26.0%) in Pakistan, while these were the lowest for Iran (10.1%).








Saudi Arabia
15.7%
35.1%
17.4%
24.3%
7.5%
Traffic (%)
Mixed sources (TIR) (%)
Industries (%)
Dust (%)
Others (%)
Egypt
3.4%
8.9%
14.0%
5.7%
68.0%
Traffic (%)
Mixed sources (TIR) (%)
Industries (%)
Dust (%)
Others (%)
Qatar
0.1%
15.0%
21.2%
11.9%
21.6%
30.2%
Traffic (%)
Mixed sources (TIR) (%)
Secondary aerosols (%)
Dust (%)
Sea salt (%)
Others (%)
Kuwait
8.0%
11.6%
31.6%
48.9%
Traffic (%)
Mixed sources (TIR) (%)
Dust (%)
Others (%)
Jordan
3.3%
4.0%
9.7%
28.7%
38.7%
13.0%
2.7%
Traffic (%)
Mixed sources (TIR) (%)
Secondary aerosols (%)
Industries (%)
Biomass burning (%)
Dust (%)
Sea salt (%)
Palestine
6.0%
3.5%
14.0%
21.0%
12.5%
42.0%
1.0%
Traffic (%)
Mixed sources (TIR) (%)
Secondary aerosols (%)
Industries (%)
Biomass burning (%)
Dust (%)
Sea salt (%)
Morocco
12.6%
34.9%
52.5%
Traffic (%)
Industries (%)
Dust (%)
Lebanon
14.5%
33.5%
35.0%
17.0%
Secondary aerosols (%)
Biomass burning (%)
Dust (%)
Others (%)

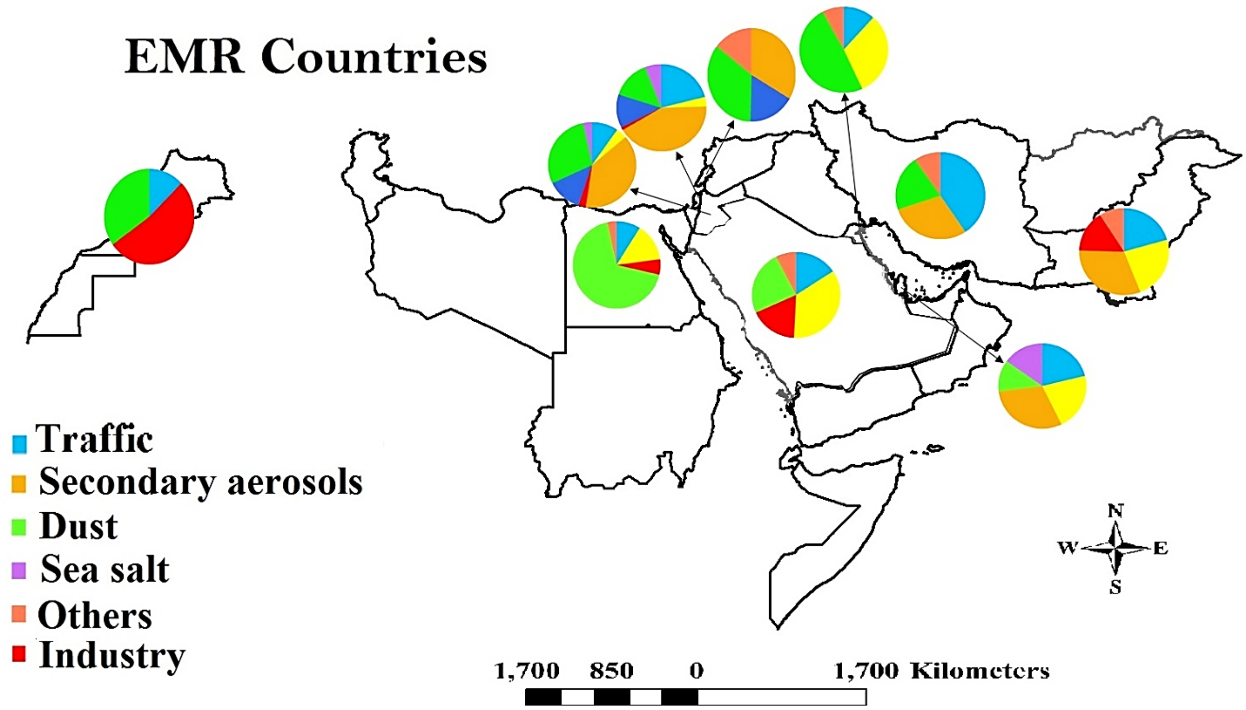
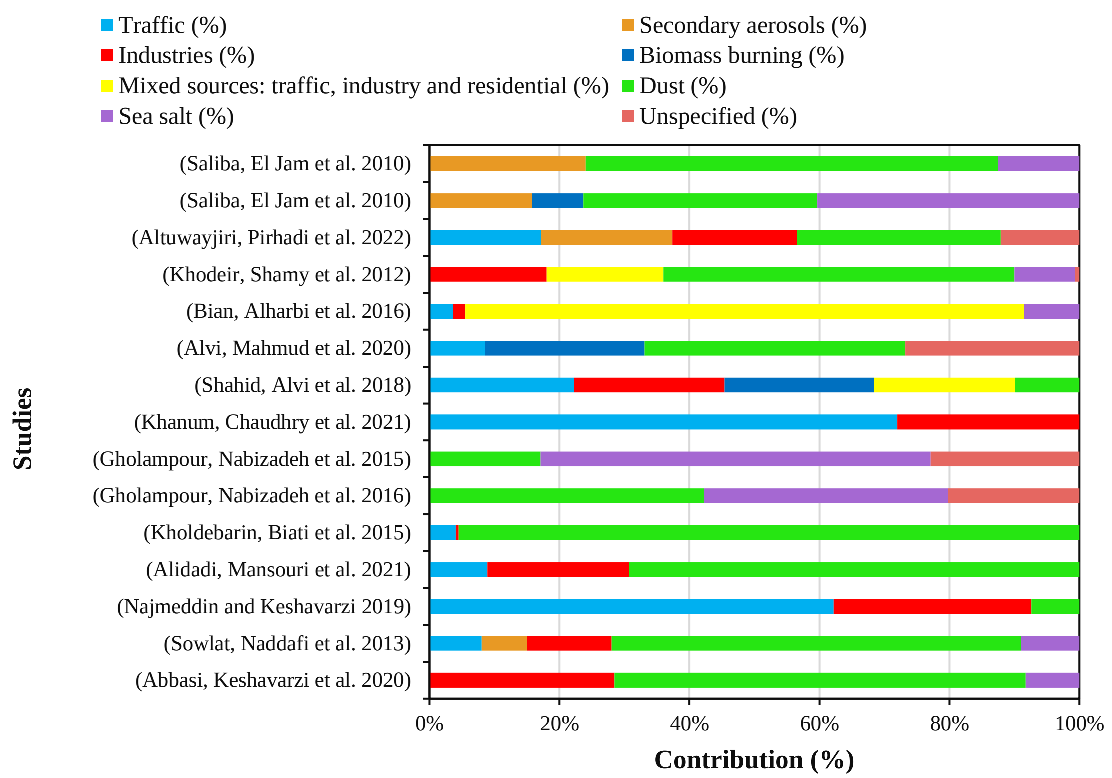


Figure 3. Relative contributions of sources to $PM_{2.5}$ mass concentrations in the included studies and the average of relative contributions of each source in the EMR countries.



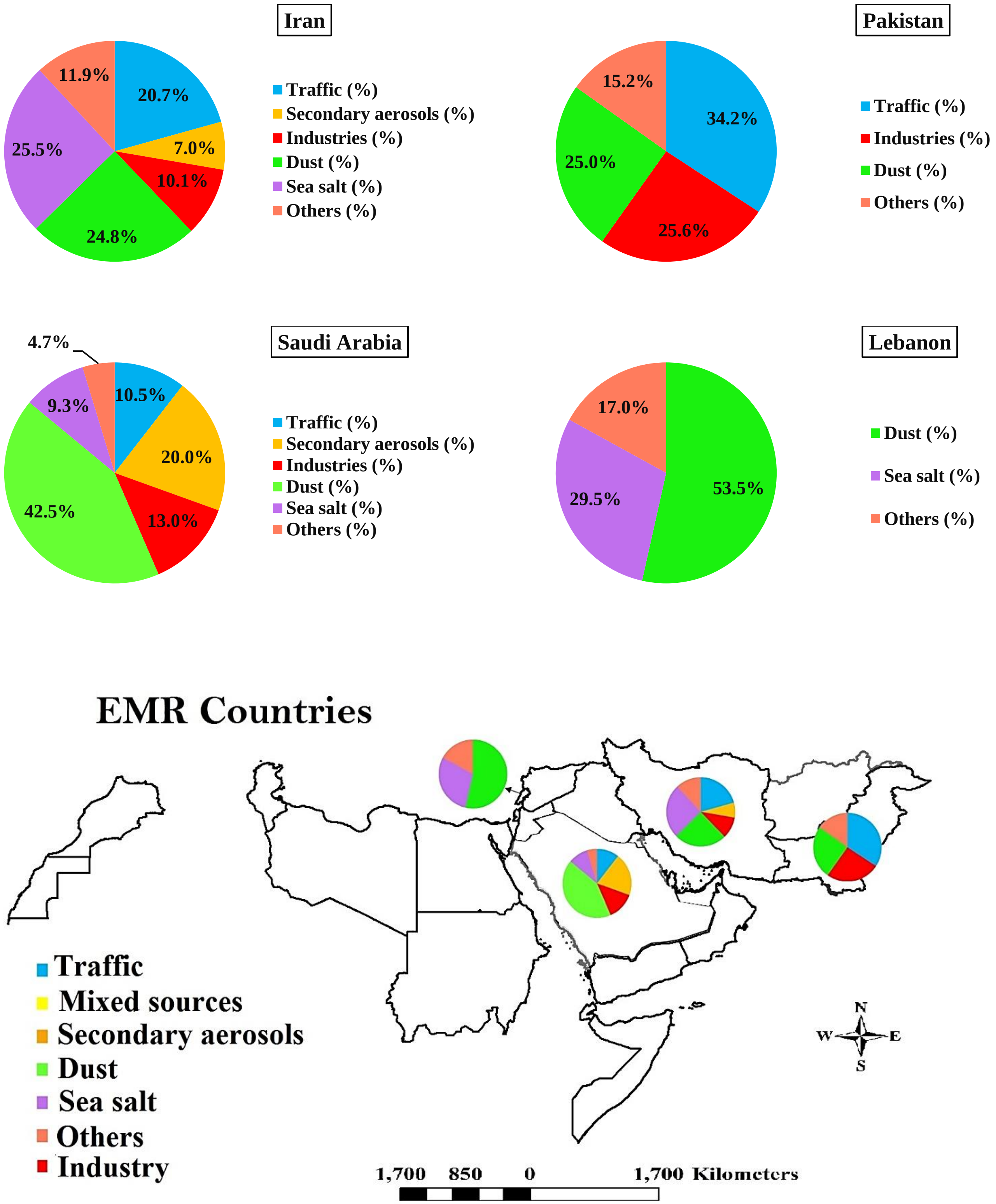


Figure 4. Relative contributions of sources to PM_{10} mass concentrations in the included studies and the average of relative contributions of each source in the EMR countries.

3.3. Comparison to previous SA studies

We have surveyed three systematic reviews regarding SA of ambient PM air pollution previously conducted at a global scale (Hopke et al. 2020; Hopke et al. 2022; Karagulian et al. 2015). Moreover, we have explored a more recently paper authored by McDuffie and colleagues on source sector and fuel contributions to ambient $PM_{2.5}$ and attributable mortality across multiple spatial scales (McDuffie et al. 2021). As shown in **Table S4**, two studies (out of three) have surveyed the contributions of sources of $PM_{2.5}$ and PM_{10} air pollution, and another study has explored SA of particle number concentrations. As reported, in the findings of our study above, we have reviewed and reported not only the included studies in these reviews but also additional studies in detail. Figure S6 gives information on the relative source of PM2.5 mass in 2017 based on the study of (McDuffie et al. 2021). As shown in **Figure S5** and **Table S5**, the study of (McDuffie et al. 2021) has specified 20 sources (AFCID (anthropogenic, fugitive, combustion, and industrial) dust, windblown dust, agriculture, energy coal, energy noncoal, industry coal, industry noncoal, nonroad transport, road transport, and others: Residential Coal Combustion, Residential Biofuel Combustion, Residential Other Combustion, Commercial Combustion, Other Combustion, Waste, International Shipping, Agricultural Waste Burning, Other Open Fire, Solvent, and Remaining Sources) for ambient $PM_{2.5}$ air pollution in all countries of the EMR. Of these sources, windblown dust with 33-78% (56% for all EMR countries, on average) had the greatest contribution in ambient $PM_{2.5}$ air pollution of all EMR countries, followed by energy (noncoal) with 1-23% (about 10% for all EMR countries, on average) and road transport with 2-11% (6% for all EMR countries, on average). The lowest contributions were reported for the sources of nonroad transport (< 1% for all EMR countries, on average) and industry (coal) (< 1% for all EMR countries, on average). Though this study has surveyed and reported the contribution of sources to $PM_{2.5}$ mass concentrations for all EMR countries, there were considerable differences with the findings of our study. Detailed information on the contribution of each of the sources to ambient $PM_{2.5}$ air pollution in all EMR countries based on the study of (McDuffie et al. 2021) is presented in **Table S5**. It should be noted that the McDuffie et al (2021) study uses a global scale dispersion model based upon an emissions inventory, and not receptor modelling based upon atmospheric measurement data and receptor modelling.

3.4. Overview of the included emission inventory studies and their findings

Table S3 shows the detailed information concerning the emission inventory studies for ambient air pollution in the EMR countries. As shown in **Table S3**, 11 studies have been conducted on the emission inventory of ambient air pollutants in 6 countries (out of 22) of the EMR. Of these studies, 6 have been conducted in Iran (five studies for Tehran and one for Mashhad city), while the remainder were conducted in Afghanistan (Kabul), Kuwait (Jahara), Pakistan (Khyber Pakhtunkhwa and Balochistan regions), Morocco (Casablanca) and Lebanon (Beirut and its 26 sub-regions). **Figure S6** reveals just relative contributions (%) of each sector to PM emissions in the EMR countries. Given Iran, the studies of (Heger and Sarraf 2018; Hosseini and Shahbazi 2016; Shahbazi et al. 2016a; Shahbazi et al. 2016b; Shahbazi et al. 2019) have reported that the mobile sources contributed on average 70% of ambient PM air pollution in Tehran, while the figures for other sources such as energy conversion, industry, household or commercial sectors and terminals were significantly lower, at 20%, 7%, 2% and 1%, respectively. Based on the study of (Shahbazi et al. 2021), nearly half of TSP, PM_{10} and $PM_{2.5}$ emissions in Mashhad was contributed by mobile sources. The second in terms of contribution was energy conversion with 32-37% of TSP, PM_{10} and $PM_{2.5}$ emissions. With regard to Lebanon (Beirut), the largest contributor to ambient PM_{10} and $PM_{2.5}$ air pollution was industry, accounting for 62% and 59%, followed by domestic sector and mobile sources (Waked et al. 2012). For Afghanistan (Kabul), the highest contribution to ambient PM_{10} emissions was attributed mobile and dust (52%), followed by domestic sector (31%) and industry (12%) (Karim 2020)

4. Perspectives and Recommendations

Ambient air pollution is a complex mixture of particulate and gaseous primary and secondary pollutants that varies in levels and composition according to time and place (Rajagopalan and Landrigan 2021). Among all air pollutants, PM air pollution has been recognized as the most notable environmental cause of respiratory-, cardiovascular-, and cancer-related deaths worldwide (Faridi et al. 2021; McDuffie et al. 2021; Rajagopalan et al. 2018; Southerland et al. 2022; Tian et al. 2019). In the recent Global Burden of Disease (GBD) study, it was indicated that exposure to $PM_{2.5}$ was globally responsible for 4.14 million (95% Confidence Interval (CI): 3.45-4.80) deaths in 2019 (GBD 2019). One of the major challenges to improve this sobering situation is to understand the origin of the ambient air pollution to make sure whether air quality plans are targeting/have targeted the major sources to ensure effective results (Hopke et al. 2020; Thunis et al. 2019). Overall, air quality plans include the following objectives: **1)** identify and quantify the sources that contribute most to air pollution levels; **2)** inform on the efficiency of mitigation strategies; **3)** identify the most appropriate measures to be applied to each of these sources and/or **4)** evaluate scenarios for future emissions to assess the effectiveness of mitigation measures to control air quality levels (Hopke et al. 2020; Thunis et al. 2019). SA studies aim at understanding the origin of ambient air pollution and are generally used for the two first inter-related tasks (Hopke et al. 2020; Thunis et al. 2019). As a result, accurately designing and conducting SA studies can affect the objectives 2, 3 and 4. Though full details are reviewed elsewhere (Hopke et al. 2020; Hopke and Jaffe 2020; Thunis et al. 2019), hereunder we introduce several recommendations for good practice in the future studies to make reported SA more useful to researchers and even policymakers.

- As mentioned above, more than 25 studies have apportioned the sources of ambient PM air pollution in the EMR countries using PCA and PCA-MLR (20 studies), SPlus Factor Analysis model with Varimax rotations (2 studies), and UNMIX (3 studies). These outdated data analysis methods have been replaced with more quantitative data analytical tools (like PMF and CMB) that provide much greater and more appropriate information on sources of variation in the data (Hopke et al. 2020; Mousavi et al. 2018; Paatero et al. 2014; Sowlat 2019). Unlike PCA, PMF is a weighted method which is able to give most weight to those chemical components with the least measurement uncertainty, hence giving more reliable results. Consequently, the more recently published studies could reanalyze their results using PMF or possibly CMB. Use of CMB depends upon availability of local chemical profiles of sources which may not be readily available. We recommend that the researchers of future studies use these approaches and tools (PMF and CMB) rather than outdated ones to specify ambient PM air pollution sources.
- As mentioned in **Table 1**, 5, 8 and 23 studies have specified the sources of ambient PM ($PM_{2.5}$, PM_{10} and $PM_{10-2.5}$) and its constituents based on < 50, 51-75 and > 100 samples using PMF.

Additionally, 5, 6 and 11 studies have specified the sources of ambient $PM_{2.5}$ air pollution based on < 50, 51-75 and > 100 samples using PMF. This tool is often used on speciated ambient $PM_{2.5}$ datasets with 10-20 chemical species > 100 samples (EPA 2015). As a general rule, the multivariate statistical methods (PMF and PCA) are unreliable unless the number of samples exceeds the number of analytical variables by at least threefold, and that criterion does not appear to have been met in all cases.

- As reported in **Figure 1**, to specifying ambient PM air pollution sources in the EMR countries, approximately half of studies (36) have analyzed just one group of chemical constituents (PAHs (19 studies) or metals (15 studies) or water-soluble ions (one study) or OC (one study)). To specify sources of air pollution precisely, it is necessary to characterize multiple chemical components of $PM_{2.5}$ and PM_{10}. When a study apportions the sources of air pollution just based on a given chemical component of PM (like PAHs or other components) the results differ compared to a study that applied the model based on a wide range of components (like PAHs + heavy metals + water soluble ions). The receptor model will provide more precise findings in order to allow adoption of better air pollution control abatement strategies, if the study can characterize a wide range of components of PM (PAHs, heavy metals, OC, EC, BC and other components). Consequently, we recommend that the researchers consider more than one generic component of PM to characterize ambient air pollution sources.
- It needs to be recognized that some of these studies are based upon short-term sampling campaigns (see **Table 1** for sampling dates), and are hence unlikely to be representative of long-term average conditions. They should hence be regarded with caution, as seasonal emission and climate factors, and even short-term weather events influence particulate matter concentrations and SA. They should therefore be regarded as indicative of, rather than defining the SA for a location. Air quality data are also site-specific, and this needs to be taken into account in data interpretation and use. There are obvious differences between roadside and urban background sites, coastal and inland sites, and those with predominantly bare soil relative to those with good ground cover. The design

of sampling programmes should aim to use sites representative of a wider area, and not just the immediate locality.

- Amongst all 22 countries in the EMR, Iran with 30 articles had the highest number of studies on source specific PM air pollution followed by Pakistan (n = 15 articles) and Saudi Arabia (n = 8 papers). Note that there were no studies in Afghanistan, Bahrain, Djibouti, Libya, Somalia, Sudan, Syria, Tunisia, United Arab Emirates and Yemen. When we are comparing the number of conducted studies in the EMR countries with their population (**Table S6**), it should be highlighted that the number of studies is almost negligible (one study per approximately 9.6 million people (71 studies per 680 million people in the EMR countries. However, this rate for Europe, North America, South America, Western Asia, South-eastern Asia, Eastern Asia (without China) and China was one study per 4.3, 2.1, 39.7, 26.1, 46.8, 9.5 and 5.7 million people respectively. Thus, the currently limited numbers of SA studies in EMR countries in comparison to Europe and North America can be augmented by additional future studies that will provide a better understanding of emission sources in the urban environment.
- Note that all included studies have been designed and conducted by researchers in the universities. In fact, the included studies have not been requested by organizations responsible for reducing ambient air pollution, or these studies have not been part of an integrated program for specifying ambient PM air pollution sources in order to design air quality plans or explore the efficiency of mitigation strategies. With regard to these issues, to accurately identify the origin of ambient air pollution constitutes as an essential step in air quality management to subsequently identify measures to control air pollution, and a much greater number of studies as part of an integrated program is needed in these countries.
- Also noteworthy is the fact that recent developments indicates that source apportionment done simultaneously with more than one receptor model (PMF + CMB) could provide more robust results (Contini et al. 2016). As a result, we suggest that the researchers consider simultaneously two receptor models to improve the robustness of their findings.

- Finally, one of the most important issues for SA is sampling instruments and analytical procedures (type of samplers employed, type of filters used and the process of its preparation before and after sampling, and analytical procedures) that are used to produce the input data for SA models and tools. Prior to conduct of the study, we recommend that the researchers read the relevant protocols and papers in detail. Full details regarding requirements for the quality of data used for SA by the more modern and statistically appropriate tools and methods like PMF and CMB are presented elsewhere (Belis et al. 2020; Hopke et al. 2020; Karagulian et al. 2015; Thunis et al. 2019).

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Supplemental file

Source Apportionment, Identification and Characterization, and Emission Inventory of Ambient Particulate Matter in 22 Eastern Mediterranean Region Countries: A Systematic Review and Recommendations for Good Practice★

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★ This study is a part of a consultancy to provide a background assessment of air quality (AQ) management system for the Eastern Mediterranean countries in order to improve their capabilities to use the updated World Health Organization Air Quality Guidelines in compiling national AQ standards.

Table S1. Full search strategy (components and the results of search) in PubMed, Scopus, and Web of Science for the source apportionment, characterization and identification studies.

Components	**Keywords**
Countries	Afghanistan Bahrain Djibouti Egypt Islamic Republic of Iran (Iran) Iraq Jordan Kuwait Lebanon Libya Morocco Occupied Palestinian territory (Palestine) Oman Pakistan Qatar Saudi Arabia Somali Sudan Syrian Arab Republic United Arab Emirates Tunisia Yemen
Air Quality	Air Pollution Air Pollutant Particulate Matter PM_{10} $PM_{2.5}$
Approaches	Source Apportionment Source Identification Source characterization
Databases	**Results**
Scopus: 196	((TITLE-ABS-KEY (*afghanistan*) OR TITLE-ABS-KEY (*bahrain*) OR TITLE-ABS-KEY (*diibouti*) OR TITLE-ABS-KEY (*egypt*) OR TITLE-ABS-KEY (*"Islamic Republic of Iran"*) OR TITLE-ABS-KEY (*iran*) OR TITLE-ABS-KEY (*iraq*) OR TITLE-ABS-KEY (*jordan*) OR TITLE-ABS-KEY (*kuwait*) OR TITLE-ABS-KEY (*lebanon*) OR TITLE-ABS-KEY (*libya*) OR TITLE-ABS-KEY (*morocco*) OR TITLE-ABS-KEY (*"Occupied Palestinian territory"*) OR TITLE-ABS-KEY (*palestinian*) OR TITLE-ABS-KEY (*oman*) OR TITLE-ABS-KEY (*pakistan*) OR TITLE-ABS-KEY (*qatar*) OR TITLE-ABS-KEY (*"Saudi Arabia"*) OR TITLE-ABS-KEY (*somali*) OR TITLE-ABS-KEY (*sudan*) OR TITLE-ABS-KEY (*"Syrian Arab Republic"*) OR TITLE-ABS-KEY (*"United Arab Emirates"*) OR TITLE-ABS-KEY (*tunisia*) OR TITLE-ABS-KEY (*yemen*))) AND ((TITLE-ABS-KEY (*"air pollution"*) OR TITLE-ABS-KEY (*"air pollutant*"*) OR TITLE-ABS-KEY (*"particulate matter"*) OR TITLE-ABS-KEY (*pm2.5*) OR TITLE-ABS-KEY (*pm10*))) AND ((TITLE-ABS-

	KEY (*"Source identification"*) OR TITLE-ABS-KEY (*"Source characterization"*) OR TITLE-ABS-KEY (*"Source apportionment"*))) AND (LIMIT-TO (DOCTYPE , *"ar"*) OR LIMIT-TO (DOCTYPE , *"re"*)) AND (LIMIT-TO (LANGUAGE , *"English"*))
PubMed: 50	((("air pollution"[MeSH Terms] OR ("air pollution"[Title/Abstract] OR "air pollutant"[Title/Abstract] OR "particulate matter"[Title/Abstract] OR "PM2.5"[Title/Abstract] OR "PM10"[Title/Abstract]))) AND ((("Iran"[Title/Abstract]) OR "Islamic Republic of Iran"[Title/Abstract] OR "Afghanistan"[Title/Abstract] OR "Bahrain"[Title/Abstract] OR "Djibouti"[Title/Abstract] OR "Egypt"[Title/Abstract] OR "Iraq"[Title/Abstract] OR "Jordan"[Title/Abstract] OR "Kuwait"[Title/Abstract] OR ("Lebanon"[Title/Abstract] OR "Libya"[Title/Abstract] OR "Morocco"[Title/Abstract] OR "Occupied Palestinian territory"[Title/Abstract] OR "Palestinian"[Title/Abstract] OR "Oman"[Title/Abstract]) OR "Pakistan"[Title/Abstract] OR "Qatar"[Title/Abstract] OR ("Saudi Arabia"[Title/Abstract] OR "Somali"[Title/Abstract] OR "Sudan"[Title/Abstract] OR "Syrian Arab Republic"[Title/Abstract] OR "United Arab Emirates"[Title/Abstract] OR "Tunisia"[Title/Abstract] OR "Yemen"[Title/Abstract])))) AND ((("Source Apportionment"[Title/Abstract]) OR ("Source Identification"[Title/Abstract])) OR ("Source characterization"[Title/Abstract]))
WOS: 87	(((TI=(Afghanistan) OR AB=(Afghanistan) OR TI=(Bahrain) OR AB=(Bahrain) OR TI=(Djibouti) OR AB=(Djibouti) OR TI=(Egypt) OR AB=(Egypt) OR TI=("Islamic Republic of Iran") OR AB=("Islamic Republic of Iran") OR TI=(Iran) OR AB=(Iran) OR TI=(Iraq) OR AB=(Iraq) OR TI=(Jordan) OR AB=(Jordan) OR TI=(Kuwait) OR AB=(Kuwait) OR TI=(Lebanon) OR AB=(Lebanon) OR TI=(Libya) OR AB=(Libya) OR TI=(Morocco) OR AB=(Morocco) OR TI=("Occupied Palestinian territory") OR AB=("Occupied Palestinian territory") OR TI=(Palestine) OR AB=(Palestine) OR TI=(Oman) OR AB=(Oman) OR TI=(Pakistan) OR AB=(Pakistan) OR TI=(Qatar) OR AB=(Qatar) OR TI=("Saudi Arabia") OR AB=("Saudi Arabia") OR TI=(Somali) OR AB=(Somali) OR TI=(Sudan) OR AB=(Sudan) OR TI=("Syrian Arab Republic") OR AB=("Syrian Arab Republic") OR TI=("United Arab Emirates") OR AB=("United Arab Emirates") OR TI=(Tunisia) OR AB=(Tunisia) OR TI=(Yemen) OR AB=(Yemen))) AND (TI=("air pollution") OR AB=("air pollution") OR TI=("Air pollutant") OR AB=("Air pollutant") OR TI=("particulate matter") OR AB=("particulate matter") OR TI=(PM2.5) OR AB=(PM2.5) OR TI=(PM10) OR AB=(PM10) AND) TI=("Source Apportionment") OR AB=("Source Apportionment") OR (TI="Source Identification") OR AB=("Source Identification") OR (TI="Source Characterization") OR AB=("Source Characterization") (AND LANGUAGE: (English)

Table S2. Full search strategy (components and the results of search) in PubMed, Scopus, and Web of Science for the emission inventory studies.

Components	**Keywords**
Countries	Afghanistan Bahrain Djibouti Egypt Islamic Republic of Iran (Iran) Iraq Jordan Kuwait Lebanon Libya Morocco Occupied Palestinian territory (Palestine) Oman Pakistan Qatar Saudi Arabia Somali Sudan Syrian Arab Republic United Arab Emirates Tunisia Yemen
Air Quality	Air Pollution Air Pollutant Particulate Matter PM_{10} $PM_{2.5}$
Approach	Emission Inventory
Databases	**Results**
Scopus: 82	(TITLE-ABS-KEY ("Emission Inventory")) AND ((TITLE-ABS-KEY ("air pollution") OR TITLE-ABS-KEY ("air pollutant") OR TITLE-ABS-KEY ("air pollutatns"))) AND ((TITLE-ABS-KEY (bahrain) OR TITLE-ABS-KEY (afghanistan) OR TITLE-ABS-KEY (djibouti) OR TITLE-ABS-KEY (egypt) OR TITLE-ABS-KEY ("Islamic Republic of Iran") OR TITLE-ABS-KEY (iran) OR TITLE-ABS-KEY (iraq) OR TITLE-ABS-KEY (jordan) OR TITLE-ABS-KEY (kuwait) OR TITLE-ABS-KEY (lebanon) OR TITLE-ABS-KEY (libya) OR TITLE-ABS-KEY (morocco) OR TITLE-ABS-KEY ("Occupied Palestinian territory") OR TITLE-ABS-KEY (palestinian) OR TITLE-ABS-KEY (oman) OR TITLE-ABS-KEY (pakistan) OR TITLE-ABS-KEY (qatar) OR TITLE-ABS-KEY ("Saudi Arabia") OR TITLE-ABS-KEY (somali) OR TITLE-ABS-KEY (sudan) OR TITLE-ABS-KEY ("Syrian Arab Republic") OR TITLE-ABS-KEY ("United Arab Emirates") OR TITLE-ABS-KEY (tunisia) OR TITLE-ABS-KEY (yemen))) AND (LIMIT-TO (LANGUAGE , "English"))

PubMed: 8	((("air pollution"[Title/Abstract] OR "air pollutant"[Title/Abstract] OR "air pollutants"[Title/Abstract]) AND "Iran"[Title/Abstract]) OR "i r iran"[Affiliation] OR "i r iran"[Title/Abstract] OR "i r iran"[Title/Abstract] OR "IR Iran"[Title/Abstract] OR "IR Iran"[Title/Abstract] OR "i r iran"[Title/Abstract] OR "Islamic Republic of Iran"[Affiliation] OR "Islamic Republic of Iran"[Title/Abstract] OR "iran islamic republic of"[Title/Abstract] OR "iran islamic republic of"[Title/Abstract] OR "iran islamic republic"[Title/Abstract] OR "iran islamic republic"[Title/Abstract] OR "Iranian"[Title/Abstract] OR "Iranians"[Title/Abstract] OR "persia*"[Title/Abstract] OR "Afghanistan"[Title/Abstract] OR "Bahrain"[Title/Abstract] OR "Djibouti"[Title/Abstract] OR "Egypt"[Title/Abstract] OR "Iraq"[Title/Abstract] OR "Jordan"[Title/Abstract] OR "Kuwait"[Title/Abstract] OR "Lebanon"[Title/Abstract] OR "Libya"[Title/Abstract] OR "Morocco"[Title/Abstract] OR "Occupied Palestinian territory"[Title/Abstract] OR "Palestinian"[Title/Abstract] OR "Oman"[Title/Abstract] OR "Pakistan"[Title/Abstract] OR "Qatar"[Title/Abstract] OR "Saudi Arabia"[Title/Abstract] OR "Somali"[Title/Abstract] OR "Sudan"[Title/Abstract] OR "Syrian Arab Republic"[Title/Abstract] OR "United Arab Emirates"[Title/Abstract] OR "Tunisia"[Title/Abstract] OR "Yemen"[Title/Abstract]) AND "Emission Inventory"[Title/Abstract]
WOS: 17	((TI=("Emission Inventory") OR AB=("Emission Inventory")) AND ((TI=(Afghanistan) OR AB=(Afghanistan) OR TI=(Bahrain) OR AB=(Bahrain) OR TI=(Djibouti) OR AB=(Djibouti) OR TI=(Egypt) OR AB=(Egypt) OR TI=("Islamic Republic of Iran") OR AB=("Islamic Republic of Iran") OR TI=(Iran) OR AB=(Iran) OR TI=(Iraq) OR AB=(Iraq) OR TI=(Jordan) OR AB=(Jordan) OR TI=(Kuwait) OR AB=(Kuwait) OR TI=(Lebanon) OR AB=(Lebanon) OR TI=(Libya) OR AB=(Libya) OR TI=(Morocco) OR AB=(Morocco) OR TI=("Occupied Palestinian territory") OR AB=("Occupied Palestinian territory") OR TI=(Palestine) OR AB=(Palestine) OR TI=(Oman) OR AB=(Oman) OR TI=(Pakistan) OR AB=(Pakistan) OR TI=(Qatar) OR AB=(Qatar) OR TI=("Saudi Arabia") OR AB=("Saudi Arabia") OR TI=(Somali) OR AB=(Somali) OR TI=(Sudan) OR AB=(Sudan) OR TI=("Syrian Arab Republic") OR AB=("Syrian Arab Republic") OR TI=("United Arab Emirates") OR AB=("United Arab Emirates") OR TI=(Tunisia) OR AB=(Tunisia) OR TI=(Yemen) OR AB=(Yemen))) AND (((TI=("Air pollution") OR AB=("Air pollution") OR TI=("Air pollutant") OR AB=("Air pollutant") OR TI=("Air pollutants") OR AB=("Air pollutants"))))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, SSCI Timespan=All years

Table S3. Detailed information concerning the emission inventory studies for ambient air pollution in the EMR countries.

Study ID	Country/City	Applied method	Air pollutants	The relative contribution (%) of sources
(Hosseini and Shahbazi, 2016; Shahbazi et al., 2019; Shahbazi et al., 2016a; Shahbazi et al., 2016b)	Iran/ Tehran	The International Vehicle Emissions (IVE) model	PM	Mobile: 70% (Passenger Cars: 2%; Taxi: 1%; Minibus: 7%; Tehran Municipal Bus: 24%; Private Sector Bus: 30; Truck: 24%; Motorcycle: 12%); Industry: 7%; Household or commercial emissions: 2%; Energy conversion: 20%; Terminals: 1%
			CO	Mobile: 98% (Passenger Cars: 51%; Taxi: 21%; Pickup: 11%; Minibus: 1%; Tehran Municipal Bus: 1%; Motorcycle: 15%); Others: 2%
			SOx	Mobile: 6% (Passenger Cars: 29%; Taxi: 3%; Pickup: 3%; Minibus: 12%; Tehran Municipal Bus: 16%; Private Sector Bus: 15%; Truck: 21%; Motorcycle: 1%); Industry: 22%; Energy conversion: 68%; Terminals: 4%
			NOx	Mobile: 46% (Passenger Cars: 37%; Taxi: 11%; Pickup: 6%; Minibus: 7%; Tehran Municipal Bus: 11%; Private Sector Bus: 10%; Truck: 13%; Motorcycle: 5%); Household or commercial emissions: 23%; Energy conversion: 25%; Others: 2%
			VOCs	Mobile: 87% (Passenger Cars: 44%; Taxi: 12%; Pickup: 9%; Minibus: 1%; Tehran Municipal Bus: 1%; Private Sector Bus: 1%; Truck: 1%; Motorcycle: 31%); Gas Station: 10.5%; Others: 2.5%
(Shahbazi et al., 2021)	Iran/ Mashhad	The International Vehicle Emissions (IVE) model	TSP	Mobile: 46%; Industry: 20%; Household and Commercial emissions: 1%; Energy Conversion: 32%; Terminals: 1%
			PM_{10}	Mobile: 45%; Industry: 18%; Household and Commercial emissions: 1%; Energy Conversion: 35%; Terminals: 1%
			$PM_{2.5}$	Mobile: 45%; Industry: 15%; Household and Commercial emissions: 1%; Energy Conversion: 37%; Terminals: 2%
			NOx	Mobile: 24%; Industry: 11%; Household and Commercial emissions: 8%; Energy Conversion: 56%; Terminals: 1%
			SOx	Mobile: 1%; Industry: 2%; Household and Commercial emissions: 0.2%; Energy Conversion: 97%; Terminals: 1%; Gas Station: 0.1%
			CO	Mobile: 96%; Industry: 2%; Household and Commercial emissions: 1%; Energy Conversion: 97%; Gas Station: 0.4%
			VOCs	Mobile: 82%; Industry: 1%; Household and Commercial emissions: 2%; Energy Conversion: 1%; Terminals: 1%; Gas Station: 13%
(Heger and Sarraf, 2018)	Iran/ Tehran	The International Vehicle Emissions (IVE) model	PM	Mobile: 70%; Industry: 7%; Household and Commercial emissions: 2%; Energy Conversion: 20%; Gas Station: 1%
Md. Masud Karim and Venkata Nukala [a]	Afghanistan/ Kabul	USEPA emission factors and USEPA regulatory dispersion model AERMOD	PM_{10}	Vehicles and Dust: 52%; Fuel combustion for space heating: 31%; Brick kilns: 12%
			NO_2	Portable generators: 19%; Residential Heating: 8%
			SO_2	Fuel combustion for space heating: 15%; Portable generators: 8%
			CO	Fuel combustion for space heating: 39%; Gasoline Vehicles: 36%
(Ettouney et al., 2009)	Kuwait/ Jahara	Industrial source complex short term model (ISCST)	SO_2	Mobile: 4%; Oil field: 34%; Power plants: 61%; Oil Refineries: 1%
			CO	Mobile: 92%; Oil field: 8%;
			NO_X	Mobile: 27.5%; Oil field: 21%; Power plants: 0.9%; Oil Refineries: 50.6%
(Khan and Ahmad, 2018)	Pakistan/ Khyber Pakhtunkhwa and Balochistan regions	The greenhouse gas and air pollution interactions and synergies (GAINS) model	SO_2	Industry: 7%; Power and heating sector: 63%; Domestic sector: 13%
(Khatami et al., 1998)	Morocco/ Casablanca	Not reported	SO_2	Industry: 94%; Transport: 3.1%; Ternary [b]: 1.7%; Ocean: 1.2%
			NO_X	Industry: 74.3%; Transport: 23.7%; Ternary: 2%
			CO	Industry: 62.7%; Transport: 37%; Ternary: 0.3%

Study ID	Country/City	Applied method	Air pollutants	The relative contribution (%) of sources
(Waked et al., 2012)	Lebanon/ Beirut and its 26 sub-regions	Emission factors and activities from EMEP/EEA air pollutant emission inventory guidebook [c] used in this work	CO	Mobile: 93%; Industry: 3%; Forest: 1%
			NO_X	Mobile: 52%; Industry: 23%; Domestic sector: 12%; Forest: 1%
			SO_2	Mobile: 11%; Industry: 73%; Forest: 1%
			PM_{10}	Mobile: 11%; Industry: 62%; Domestic sector: 15%; Forest: 4%
			$PM_{2.5}$	Mobile: 11%; Industry: 59%; Domestic sector: 20%; Forest: 6%

[a] https://www.researchgate.net/publication/341879689_Emission_Inventory_and_Air_Quality_Dispersion_Modeling_of_Kabul_City

[b] Emissions from the public and private administrations and services (hotels, hospitals, public offices, banks, trade offices, etc.)

[c] https://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009

Table S4. Summary of information on the previously conducted systematic review studies at global scale in comparison to our study.

Study ID	Title	Summary on the approach used to identify studies	EMR countries (cities, and # of studies) reviewed in the studies	EMR countries (cities, and # of studies) reviewed in our systematic review study	Comments
(Karagulian et al., 2015)	Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level	Systematic Scopus and Google searches were performed to retrieve city studies of source apportionment for particulate matter. The research covered the period between 1990 and 2014 (year of publication).	**Pakistan** (Karachi and Lahore, and 3 studies), **Iran** (Ahvaz, and 1 study), **Saudi Arabia** (Jeddah, and 1 study), **Egypt** (Cairo, and 1 study), **Kuwait** (Kuwait, and 1 study)	**Iran** (Tehran, Shiraz, Karaj, Urmia, Bushehr, Tabriz, Isfahan, Ahvaz, and Asaluyeh, and 30 studies), **Saudi Arabia** (Riyadh, Makkah, Jeddah, and Rabigh, and 8 studies), **Pakistan** (Karachi, Lahore, Islamabad, Faisalabad, Rawalpindi, Multan, Quetta, Peshawar and Gilgit, and 15 studies), **Egypt** (Cairo and Alexandria, and 5 studies), **Kuwait** (Kuwait city, Ali Sabah Al-Salem, Fahaheel, and Kuwait, and 3 studies), **Lebanon** (Beirut, and 3 studies), **Qatar** (Doha, and 2 studies), **Jordan** (Amman, Aqaba, and Rachma, 2 studies), and **Palestine** (East Jerusalem, and Hebron, and 2 studies), **Iraq** (Baghdad, and 1 study), **Morocco** (Kenitra, and 1 study) and **Oman** (Sohar and 1 study)	As stated the findings of our study on the name of countries and cities under investigation as well as the number of studies in comparison to previous works reported in the two previous columns, we have reviewed and reported not only the included studies in these reviews but also additional studies in detail.
(Hopke et al., 2020)	Global review of recent source apportionments for airborne particulate matter	Searches were performed using the Web of Science, SCOPUS, and Google Scholar using the relevant keywords to identify the published papers since 2014 through December 2019	**Iran** (Tehran, Ahvaz and Asaluyeh County, and 7 studies), **Pakistan** (Karachi and Lahore, and 3 studies), **Saudi Arabia** (Makkah and Rabigh, and 3 studies), **Jordan** (Amman, Aqaba and Rachma, and 1 study), **Palestine** (East Jerusalem and Hebron, and 1 study), **Qatar** (Doha, and 1 study), **Iraq** (Baghdad, and 1 study) and **Tunisia** (Tunis, and 1 study)		
(Hopke et al., 2022)	Source apportionment of particle number concentrations: A global review	Searches were performed for papers published prior to August 1, 2021 using the Web of Science, SCOPUS, and Google Scholar with the relevant keywords.	**Kuwait** (Fahaheel, and 1 study)		

Table S5. Detailed information on the contribution of each of sources to ambient $PM_{2.5}$ air pollution in all EMR countries based on the study of (McDuffie et al., 2021).

Country Name	AFCID Dust (%)	Windblown Dust (%)	Agriculture (%)	Energy Coal (%)	Energy NonCoal (%)	Industry Coal (%)	Industry NonCoal (%)	NonRoad Transport (%)	Road Transport (%)	Others (%)*	Residential Coal Combustion (%)	Residential Biofuel Combustion (%)	Residential Other Combustion (%)	Commercial Combustion (%)	Other Combustion (%)	Waste (%)	International Shipping (%)	Agricultural Waste Burning (%)	Other Open Fire (%)	Remaining Sources (%)	Solvent (%)
Afghanistan	5.1	51.8	5.2	6.6	5	2.2	2.7	0.1	6.2	15.1	0	7.3	0.2	0.2	0.1	3.9	0.1	0	0.5	2.8	-0.2
Bahrain	1.3	55.7	2.9	1.1	22.9	0.4	5.7	0	6.9	3.1	0.1	0.4	0.1	0.1	0.1	1.1	0.1	0	0	1.1	-0.1
Egypt	11.8	42	5.6	5.4	6.3	0.6	4.7	0.5	5.8	17.3	0.2	3.5	0.3	0.3	0.5	5.8	1.9	0.3	0.1	4.7	-0.2
Iran	3.8	52.9	8.1	1.7	9.8	0.4	5.2	0.1	11	7	0.1	1	0.4	0.4	0.6	2.6	0.3	0.2	0.5	0.9	0
Iraq	4.3	56.6	5.1	3.4	11.1	0.6	3.7	0.1	9	6.1	0.2	0.7	0.3	0.3	0.3	3.8	0.3	0.2	0.2		-0.1
Jordan	4.6	44	8.9	8.9	9.4	1	4.4	0.3	6.8	11.7	0.3	1.5	0.2	0.5	0.3	3.4	0.9	0.2	0.1	4.6	-0.2
Kuwait	1.6	66.2	3.5	1.5	15.2	0.3	3.6	0	6.1	2	0.1	0.4	0.1	0.2	0.1	2.2	0.2	0.1	0.1		-0.1
Lebanon	4.9	39.3	8.7	9.2	11.6	1.4	4.2	0.3	6	14.4	0.5	1.8	0.2	0.6	0.4	3.9	0.9	0.3	0.1	5.7	-0.1
Libya	1.9	77.4	1.5	2.1	1.2	0.2	1.1	0.2	3.3	11.1	0.2	1.6	0.7	0.2	0.2	0.6	0.9	0.3	0.5	6.1	-0.1
Morocco	3.3	66.3	3.4	1.8	1.6	0.1	2.7	0.3	5.4	15.1	0	2.6	0.1	1.4	0.5	2	3.3	0.1	0.6	4.5	-0.1
Palestine	5.6	38.9	9.8	9.7	9.4	1	4.5	0.3	7.1	13.7	0.3	1.7	0.2	0.5	0.3	3.9	1.2	0.3	0.1	5.3	-0.2
Oman	1.3	73.5	1.7	0.9	8.5	0.8	4.4	0	3.6	5.3	0.1	1.4	0.1	0.1	0.1	0.7	0.9	0	0.1	2	-0.1
Qatar	1.3	58.8	2.8	1	20.9	0.4	5.4	0	6.4	3	0.1	0.4	0.1	0.1	0.1	1	0.1	0	0	1.1	-0.1
Saudi Arabia	1.6	63.7	2.7	1.6	13.8	0.4	6.8	0.1	5.1	4.2	0.1	0.9	0.1	0.1	0.1	1.3	0.5	0.1	0.1	1.1	-0.1
Sudan	2.1	78	0.7	1.1	4.4	0.2	2.4	0.1	2.4	8.6	0.1	2.3	0.1	0.5	0.1	1.1	0.4	0.2	1.3	2.8	0
Syria	6.9	38.9	8.9	9.1	8.3	1.7	4.2	0.3	6.7	15	0.7	1.7	0.4	0.9	0.6	4.5	0.8	0.5	0.2	4.9	-0.2
Tunisia	16.4	33	3.8	2.2	3.4	0.3	4.1	0.5	9.6	26.7	0.2	5.3	1	0.5	1	2.8	4.9	0.4	1.1	9.7	-0.2
United Arab Emirates	1.4	65	2.8	0.7	14.6	1	5.9	0	5.3	3.3	0	0.7	0.1	0.1	0.1	0.8	0.5	0	0.1	1	-0.1
Yemen	2.1	63.2	2.2	1.5	11.7	0.8	5	0.1	3.9	9.5	0.1	2	0.1	0.2	0.1	2.2	1.1	0.1	0.2	3.6	-0.1

* The sum of the next columns.

Table S6. The number of conducted studies per population in the different continents or regions of the world.

Continent or region	Population (million)	Number of conducted studies	Ratio (study per population)	Reference
EMR countries	680	71	1 study per 9.6 million	Present study
Europe	748	174	1 study per 4.3 million	(Hopke et al., 2020)
North America	373	175	1 study per 2.1 million	
South America	437	11	1 study per 39.7 million	
Western Asia	313	12	1 study per 26.1 million	
South-eastern Asia	655	14	1 study per 46.8 million	
Eastern Asia (without China)	255	27	1 study per 9.5 million	
China	1.4 billion	246	1 study per 5.7 million	

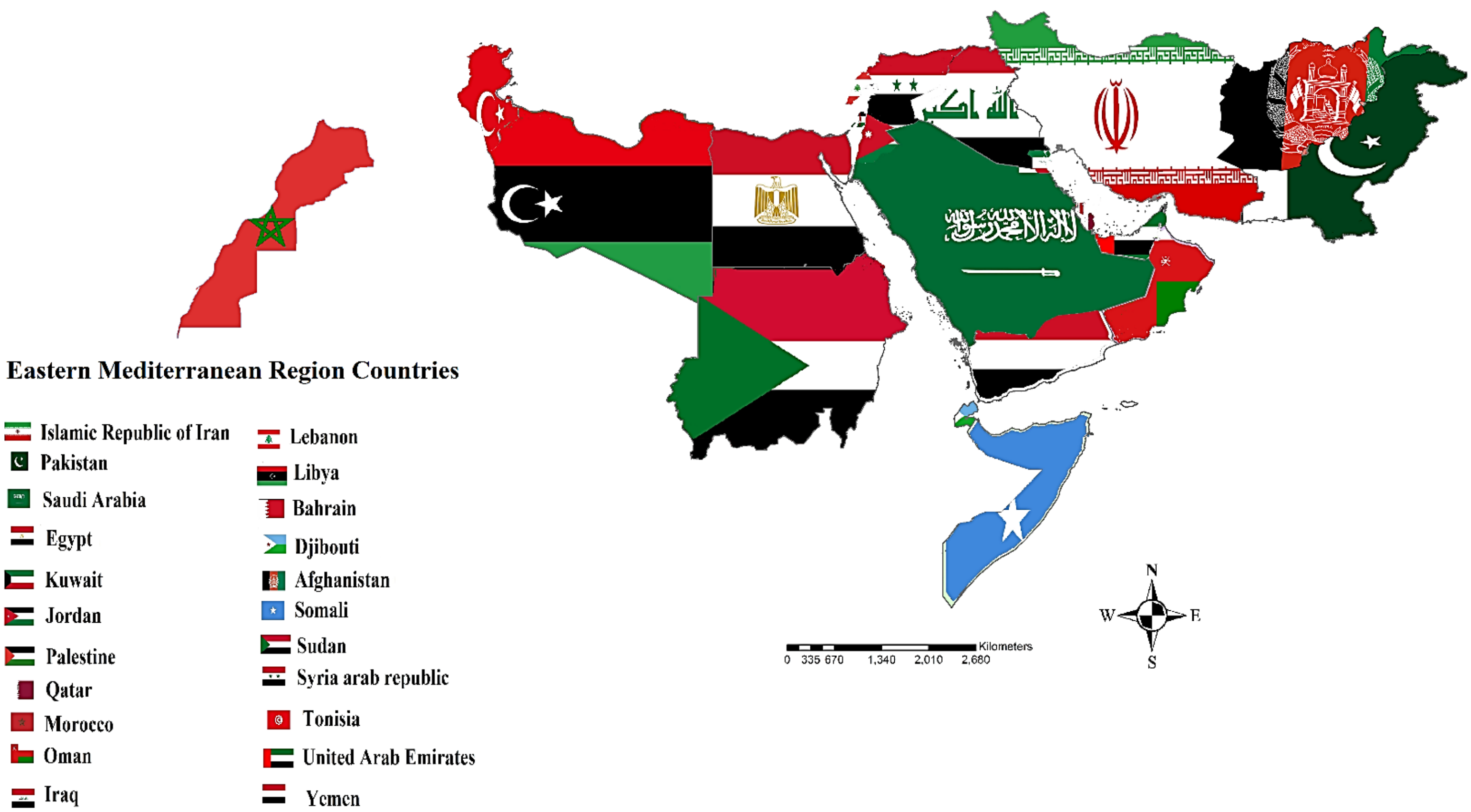
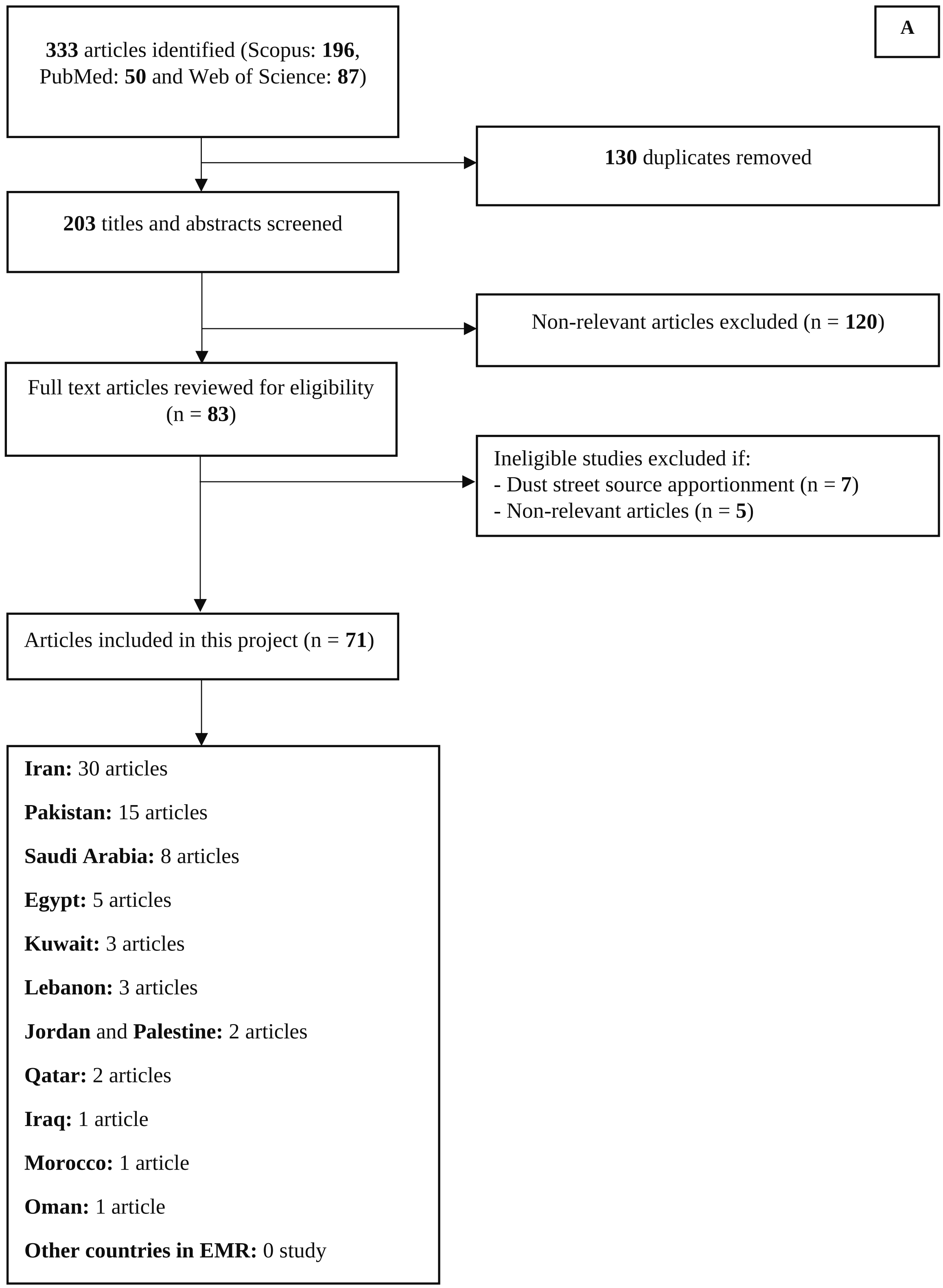


Figure S1. Spatial distribution of 22 EMR countries.


A
333 articles identified (Scopus: 196, PubMed: 50 and Web of Science: 87)
130 duplicates removed
203 titles and abstracts screened
Non-relevant articles excluded (n = 120)
Full text articles reviewed for eligibility (n = 83)
Ineligible studies excluded if:
- Dust street source apportionment (n = 7)
- Non-relevant articles (n = 5)
Articles included in this project (n = 71)
Iran: 30 articles
Pakistan: 15 articles
Saudi Arabia: 8 articles
Egypt: 5 articles
Kuwait: 3 articles
Lebanon: 3 articles
Jordan and Palestine: 2 articles
Qatar: 2 articles
Iraq: 1 article
Morocco: 1 article
Oman: 1 article
Other countries in EMR: 0 study

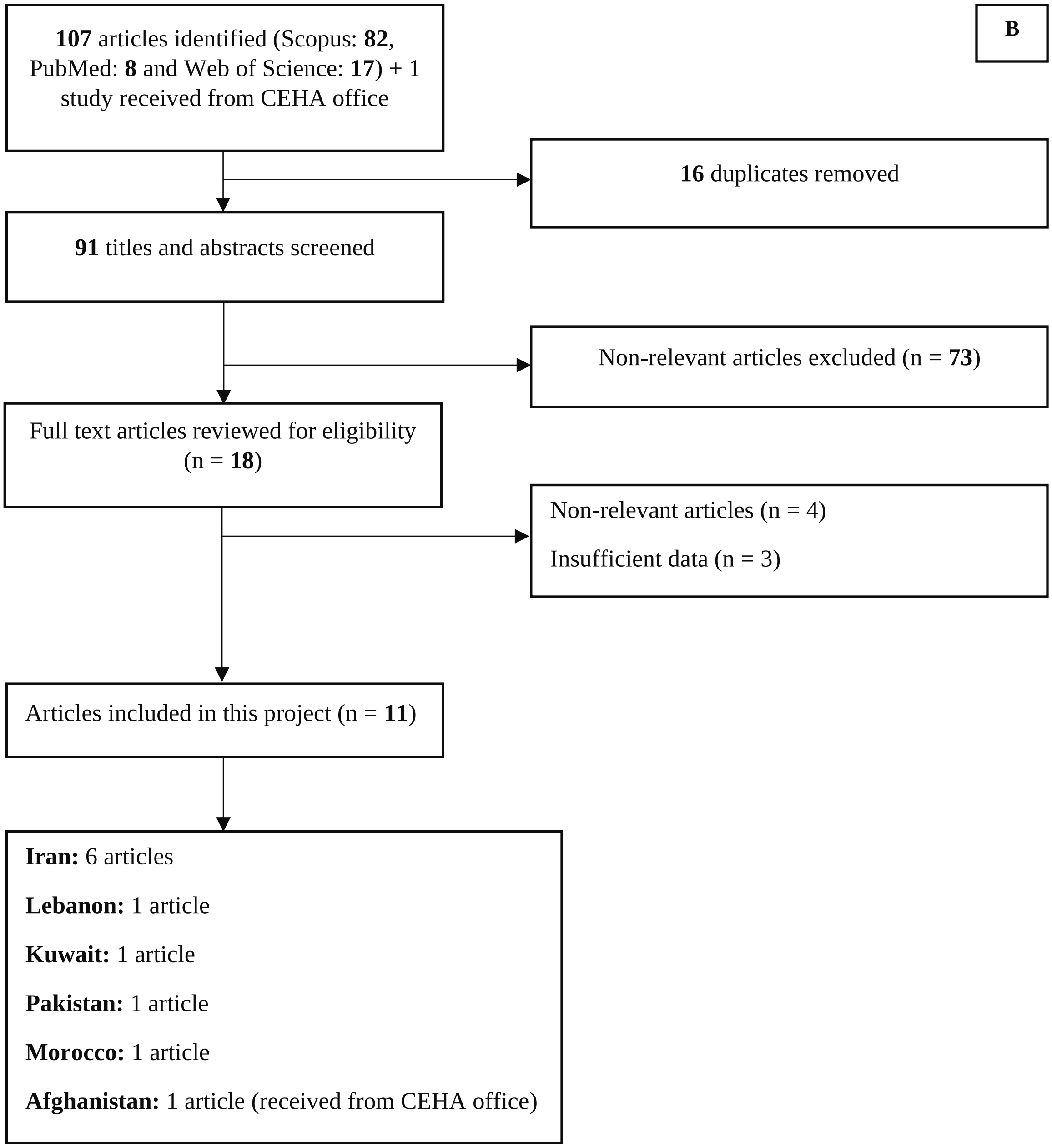


Figure S2. Flowchart illustrating the stages of the literature search on the SA, identification and characterization of PM studies (**A**) as well as emission inventories (**B**) in 22 EMR countries.

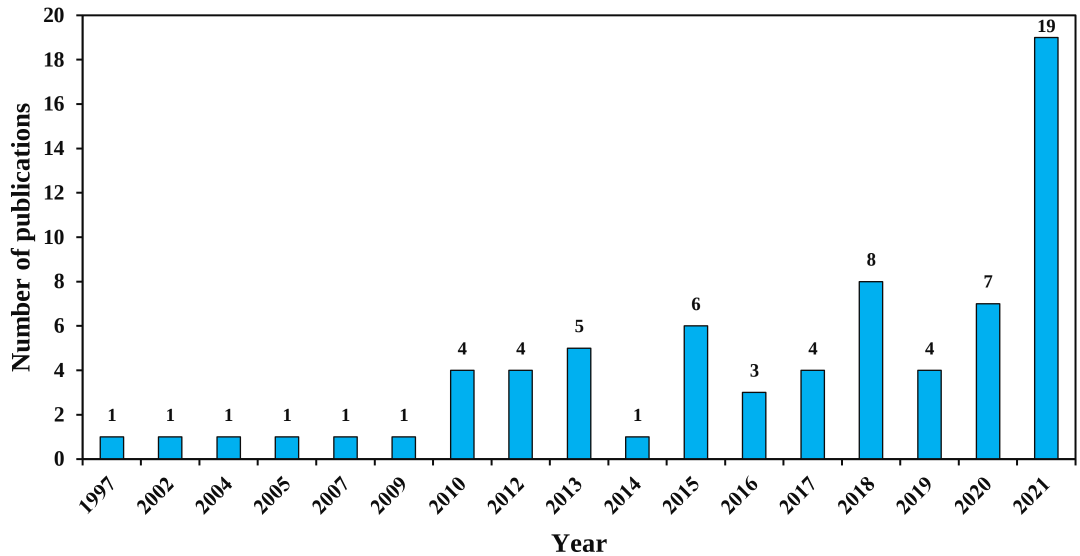


Figure S3. Chronology of source apportionment, identification and characterization studies over the EMR countries.

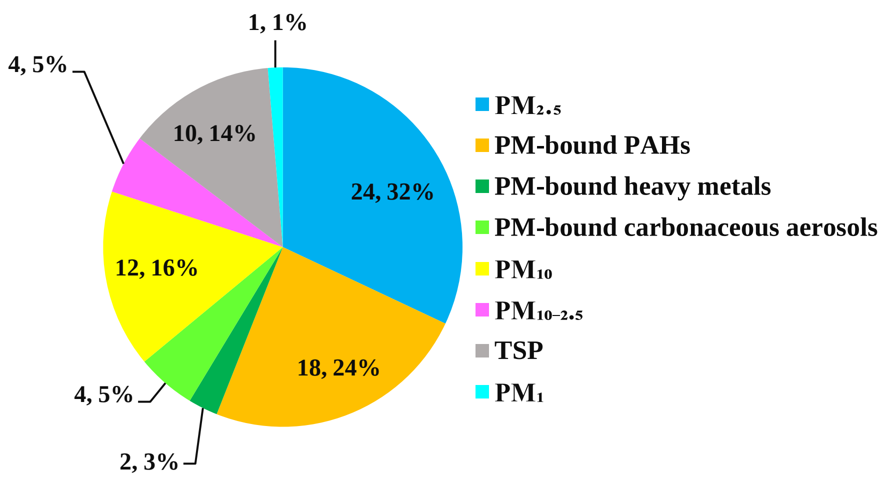


Figure S4. Pie chart of the number of papers from the EMR countries with the listed particle metric.

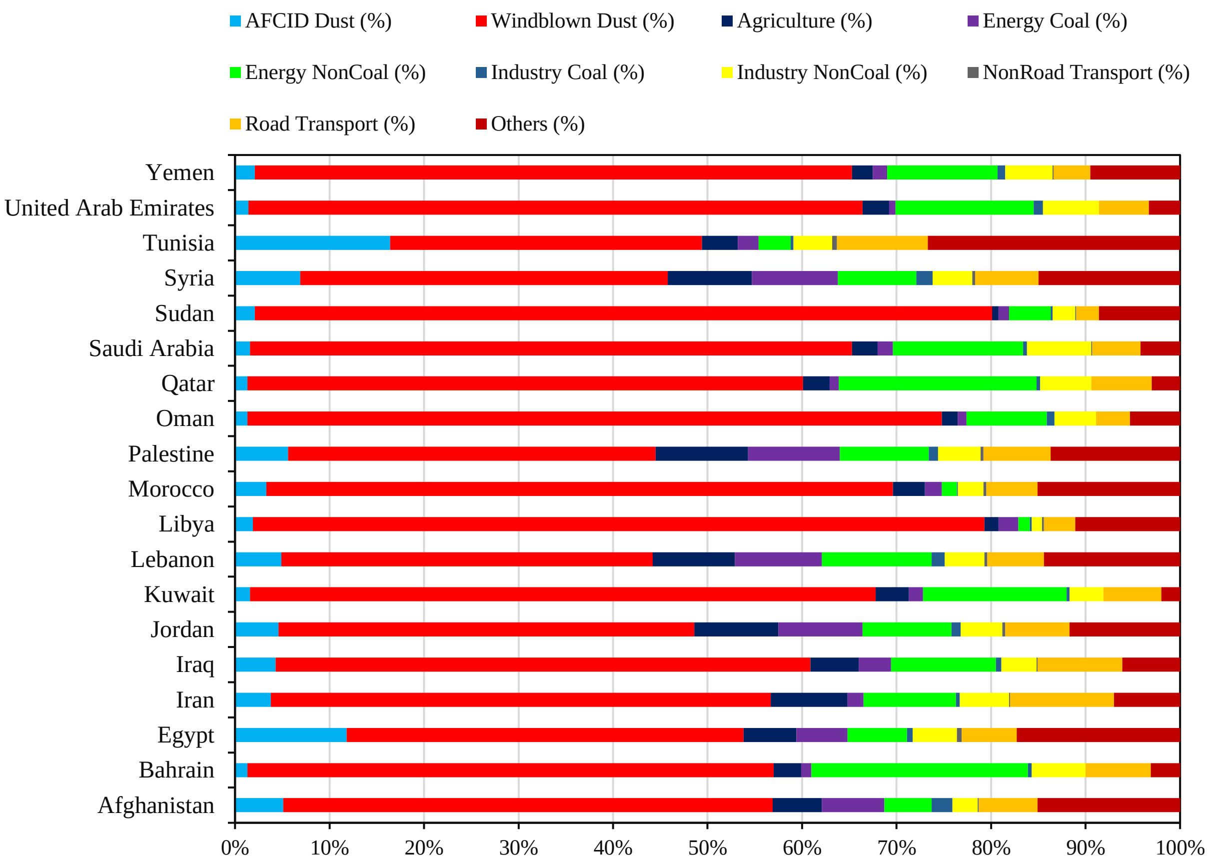
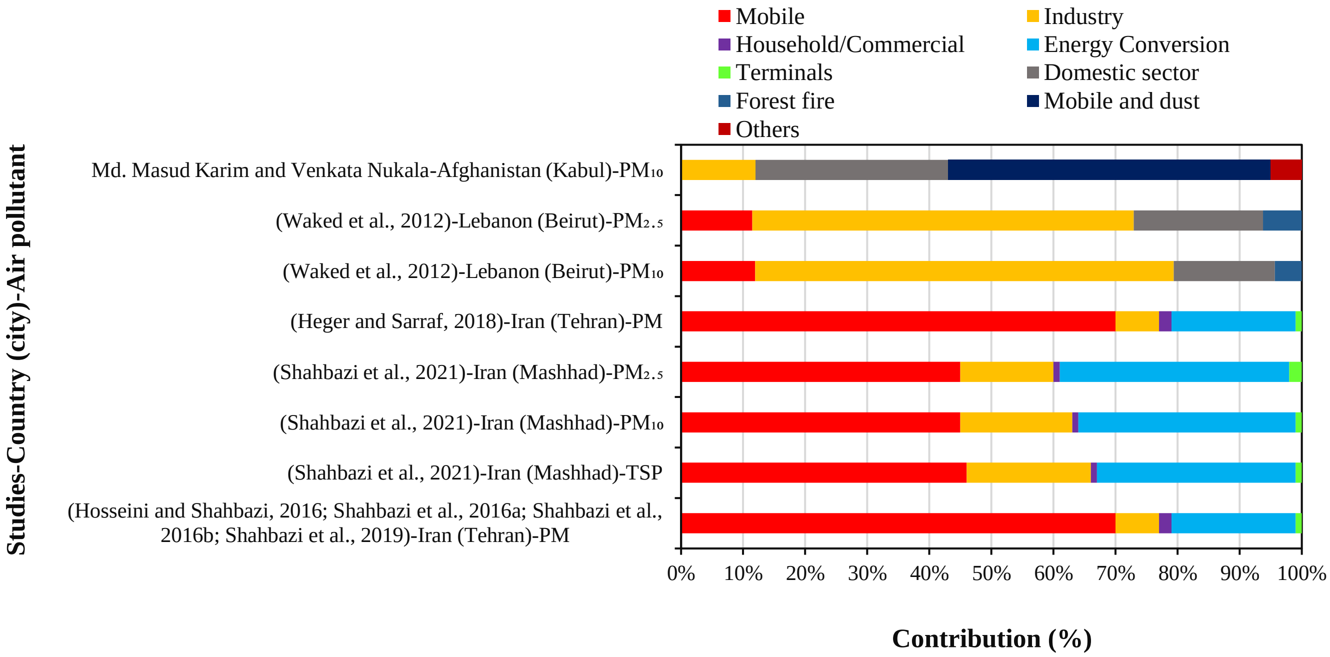


Figure S5. Relative (fractional) source of $PM_{2.5}$ mass in 2017 based on the study of (McDuffie et al., 2021).



<u>Figure S6.</u> Relative contributions (%) of each sector to PM emissions in the EMR countries based on the conducted emission inventory studies.

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