Performance Evaluation of FBC-DPF Using PEMS

The first study in Iran under real-world driving application of DPF

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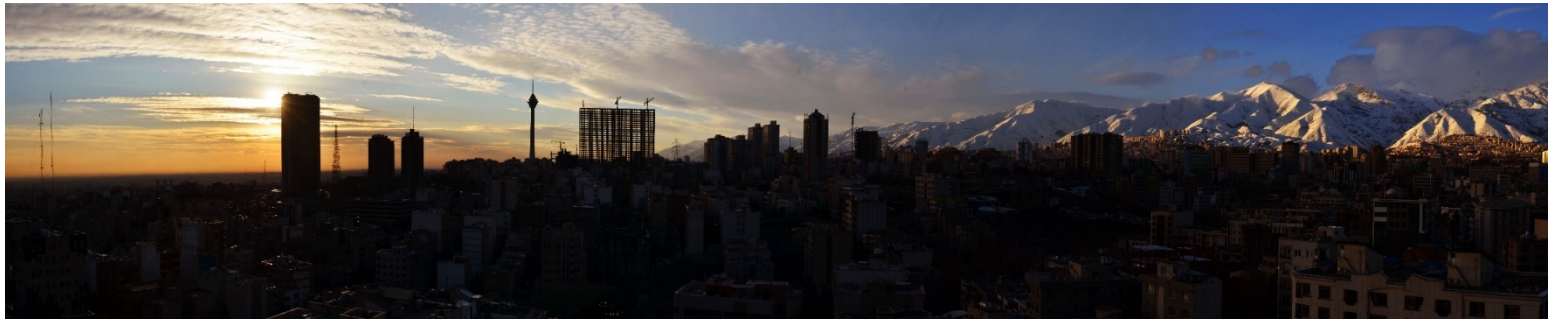
22nd ETH-Conference on Combustion Generated Nanoparticles
June 2018, Zurich, Switzerland

- TTM consulting
- augrina consulting

Pictures from Tehran



- Population: 8.5 million
- 4 million LDVs and motorcycles all gasoline and CNG
- 130,000 HDVs, all diesel

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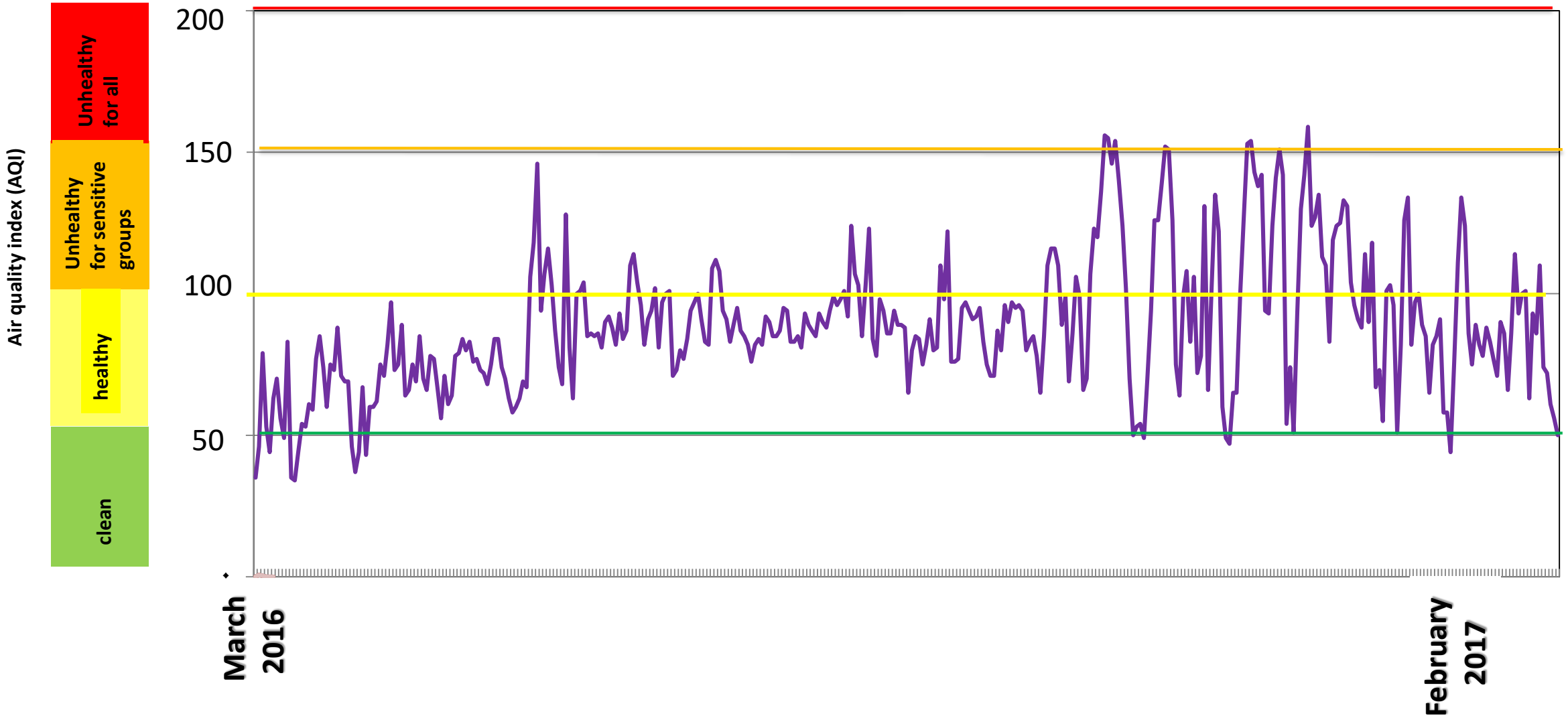
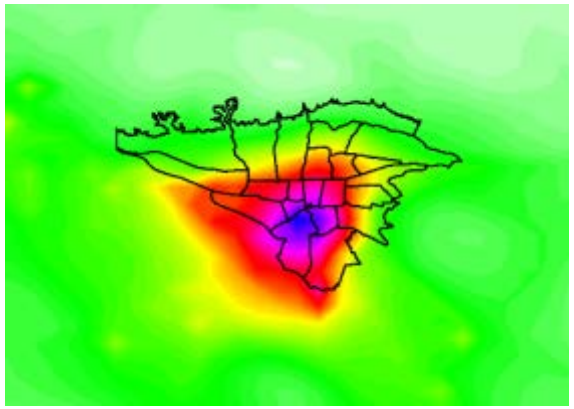
(2016-2017) AQI for Iranian calendar 1395



PM2.5 maps for the Fall & Winter of 2016, monthly average

(atmospheric chemical and transport models)



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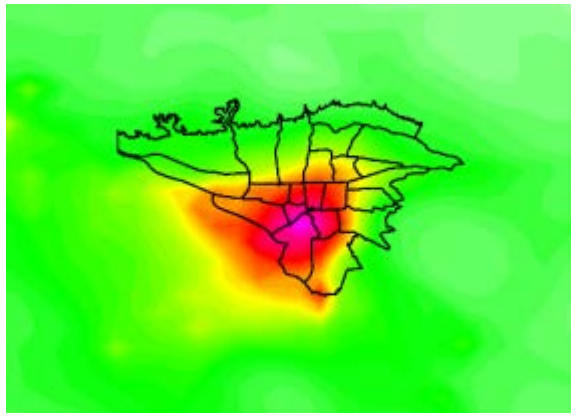

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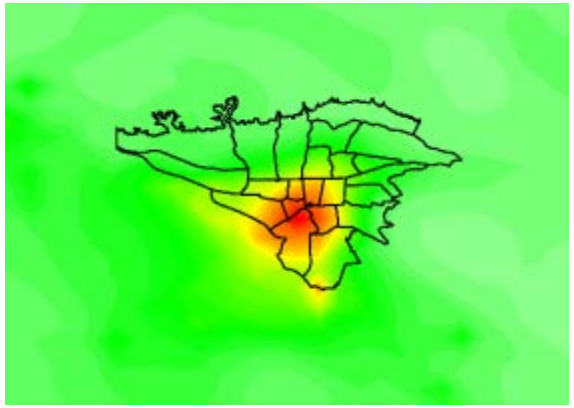

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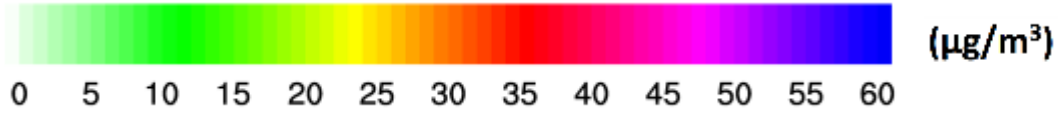

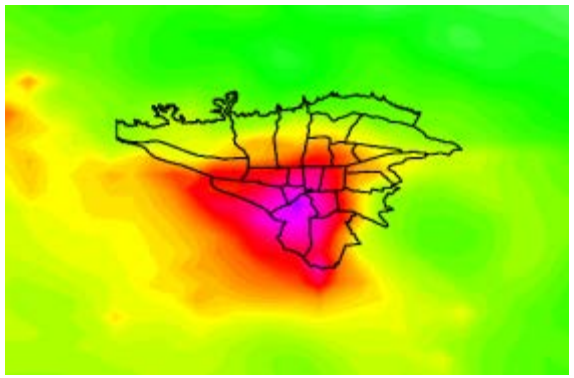

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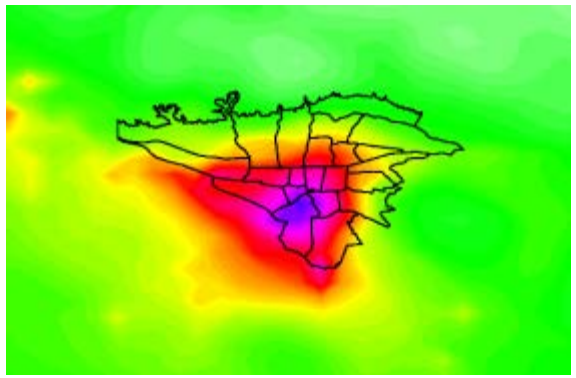

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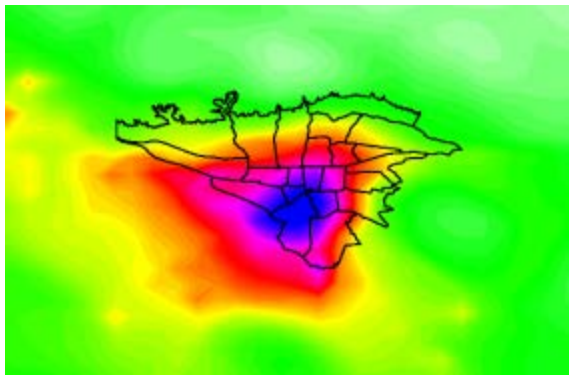


Dec

Emission inventory approach – source contributions

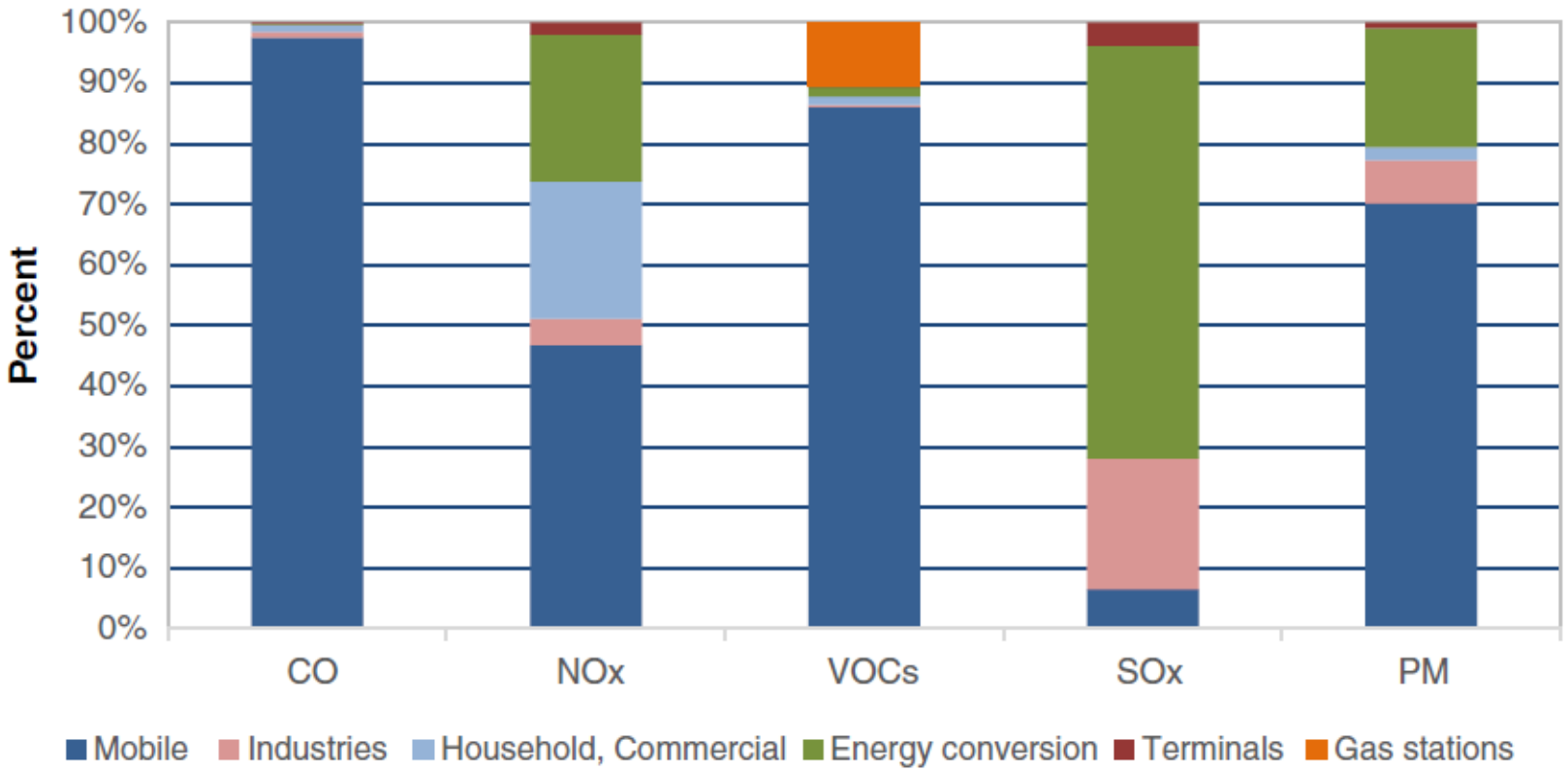
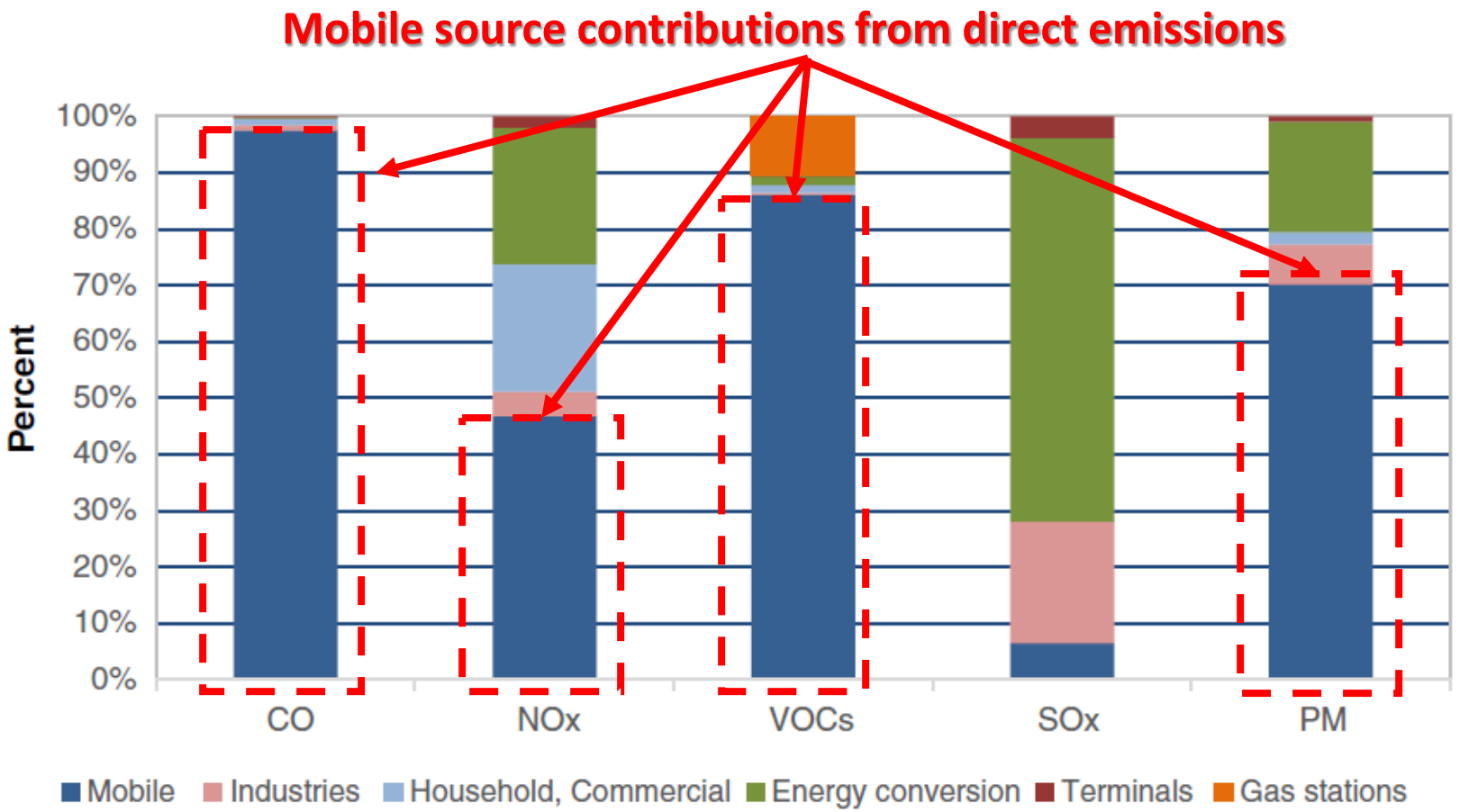


Fig. 3. Sectoral contributions to air pollution emission in Tehran for the base year of 2013.

Emission inventory approach – source contributions



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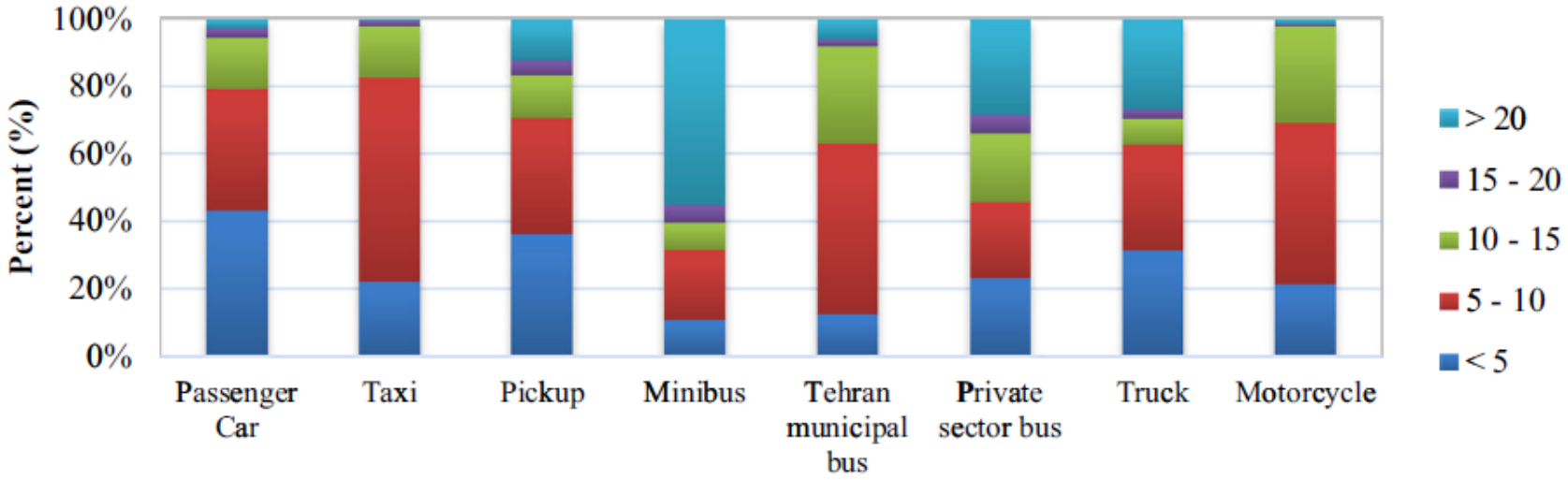
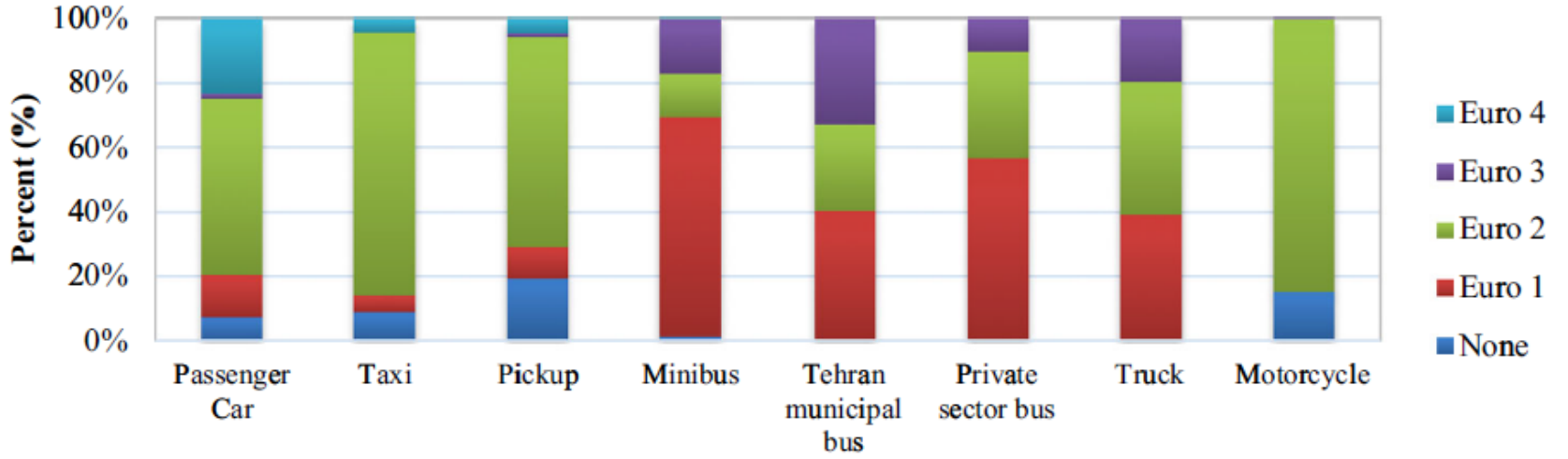
Looking at Tehran fleet age and emission standards

(Based on license plate registration data, 2013)





Emiss. Control Sci. Technol. (2016) 2:44–56

Looking at Tehran fleet age and emission standards

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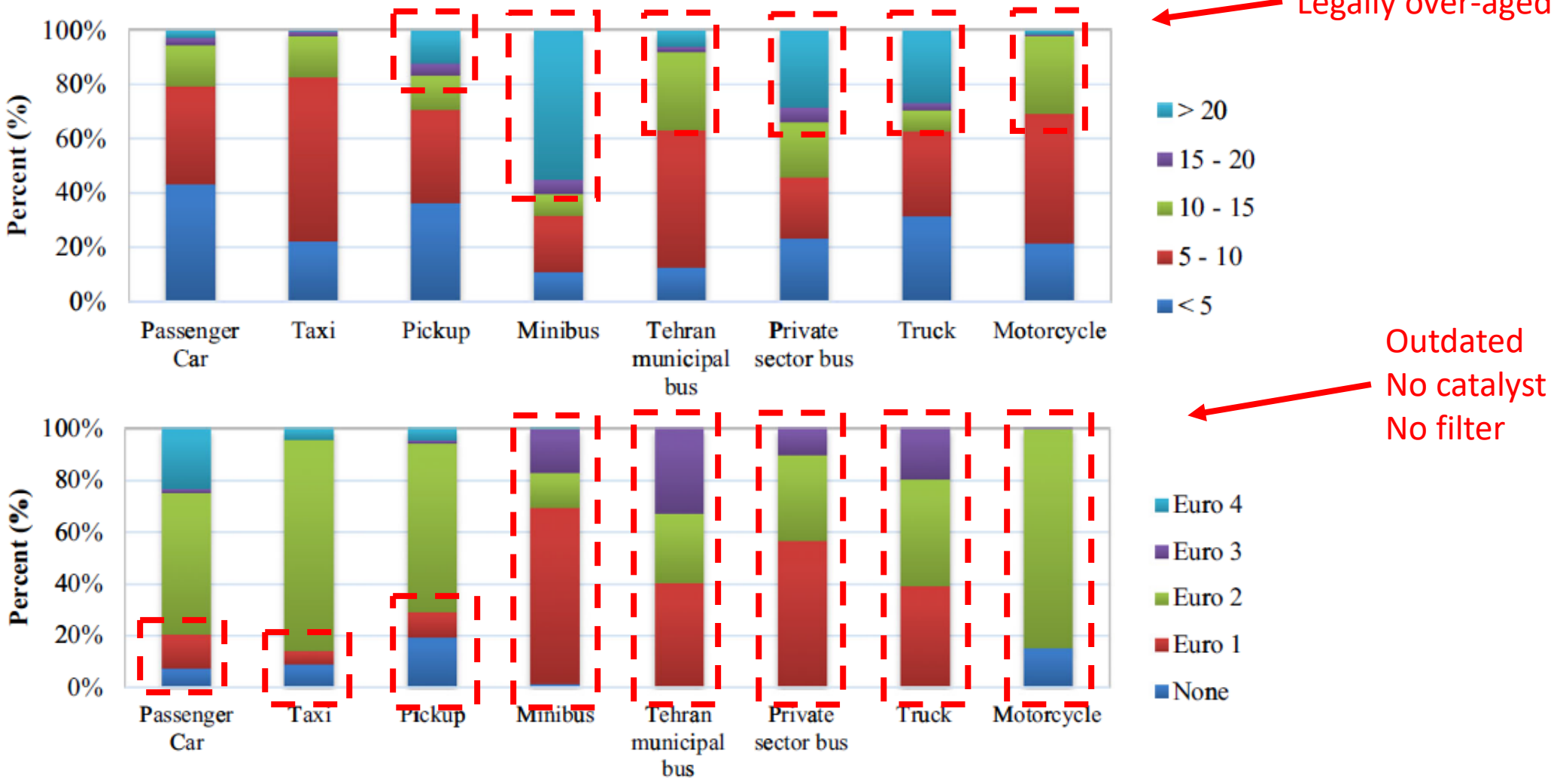

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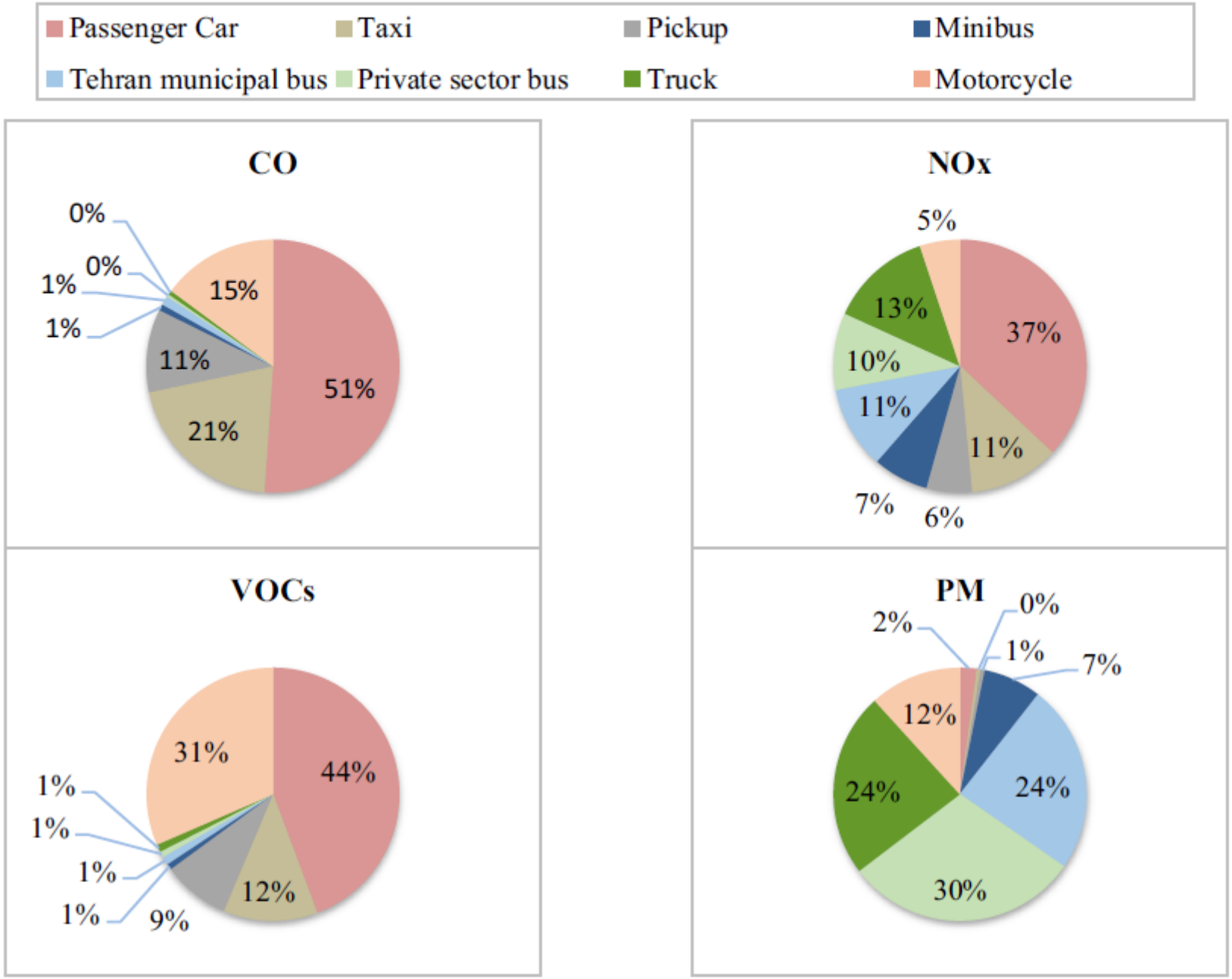
Divisions between various fleets among mobile sources



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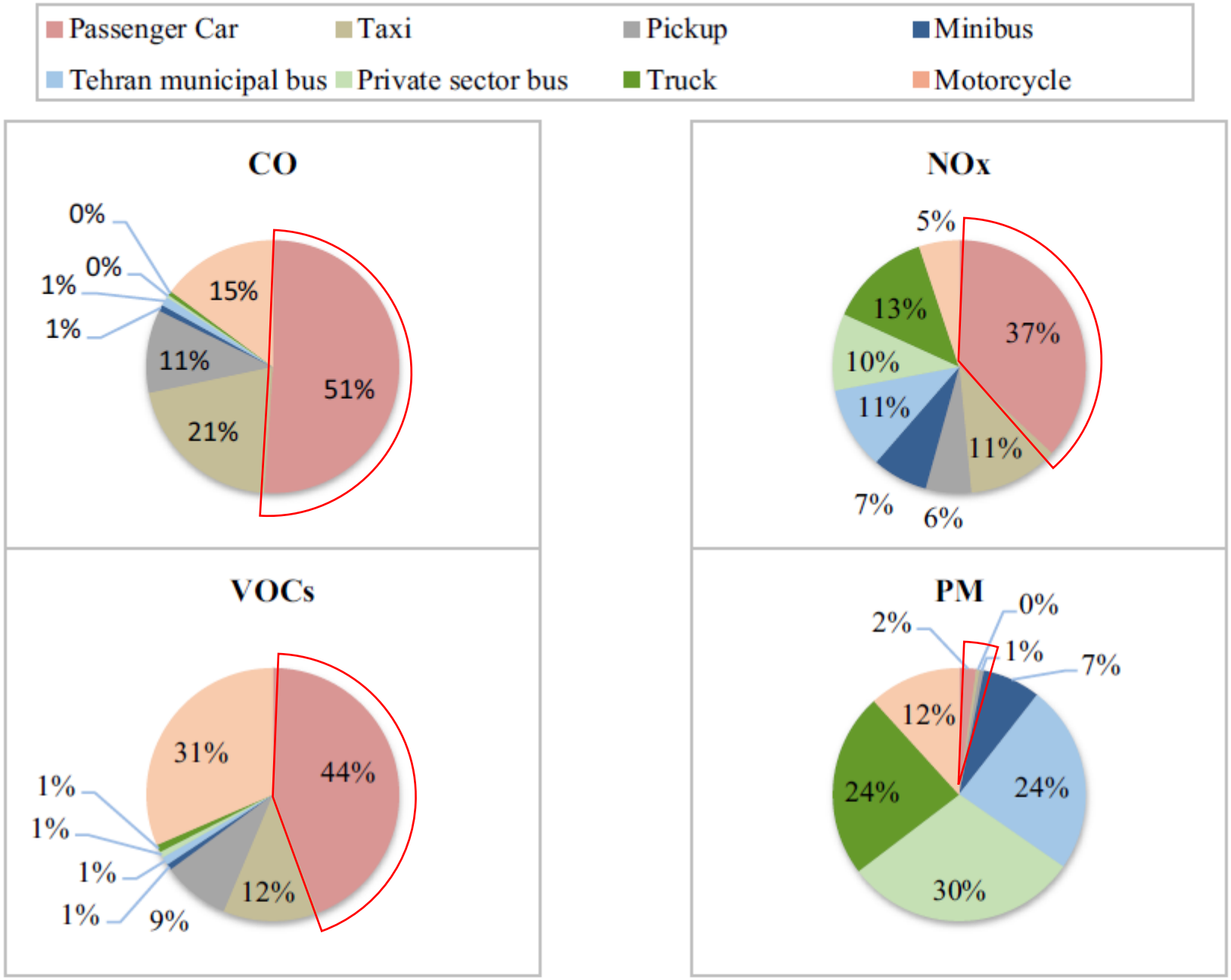
Gasoline and CNG vehicles



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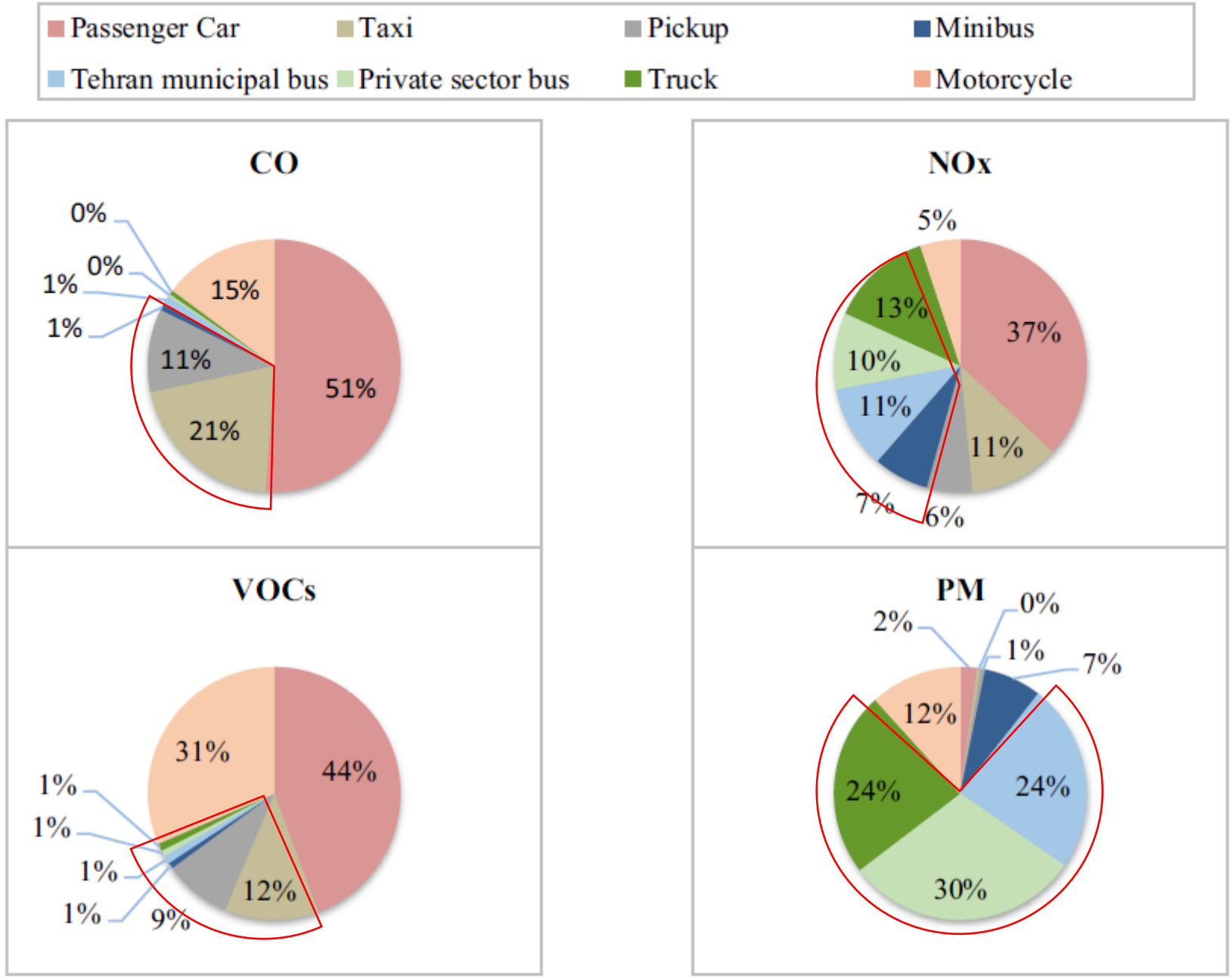
Diesel vehicles



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PM2.5 source apportionment study (Sharif University & University of Wisconsin-Madison)

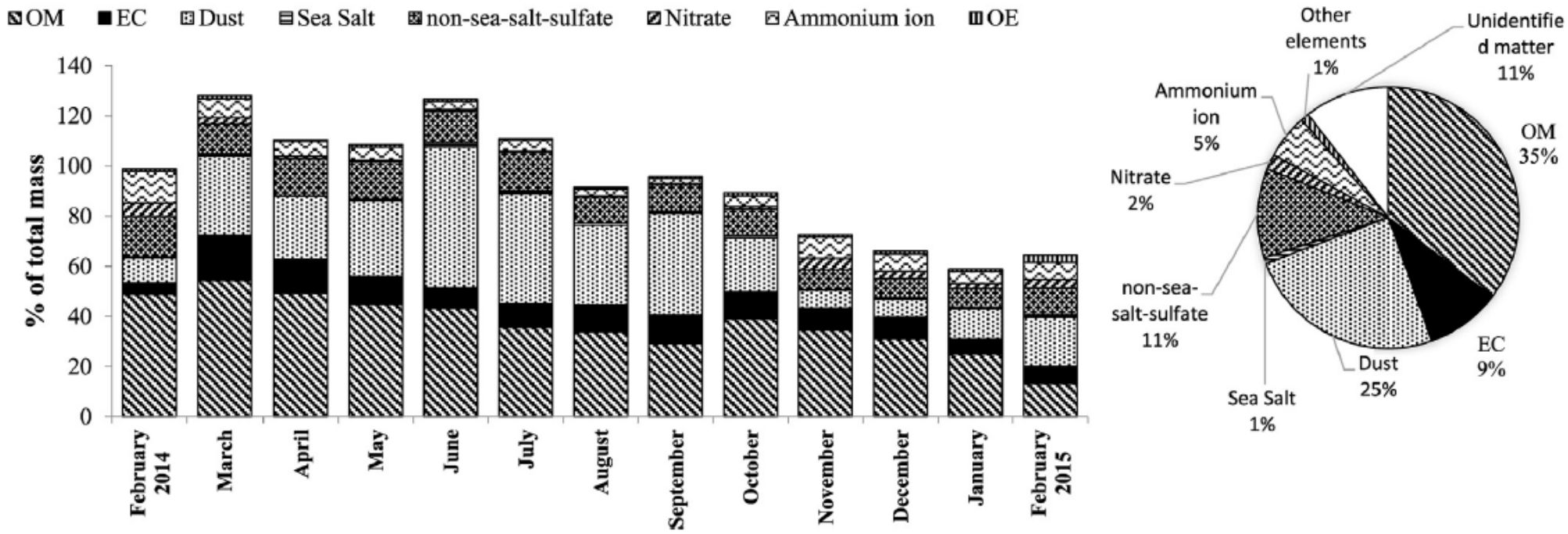

Fig. 2. The contribution of major mass constituents to $PM_{2.5}$ in Central Tehran.

M. Arhami et al. / Atmospheric Environment 153 (2017) 70–82

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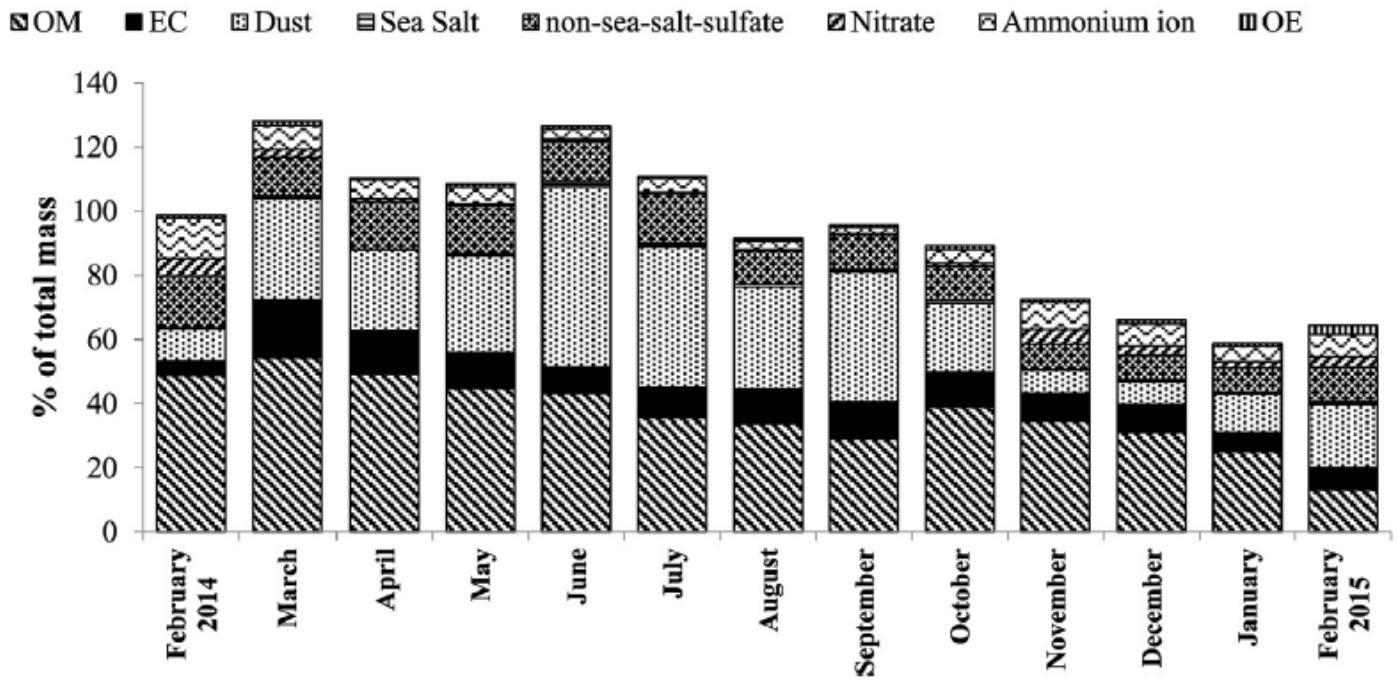

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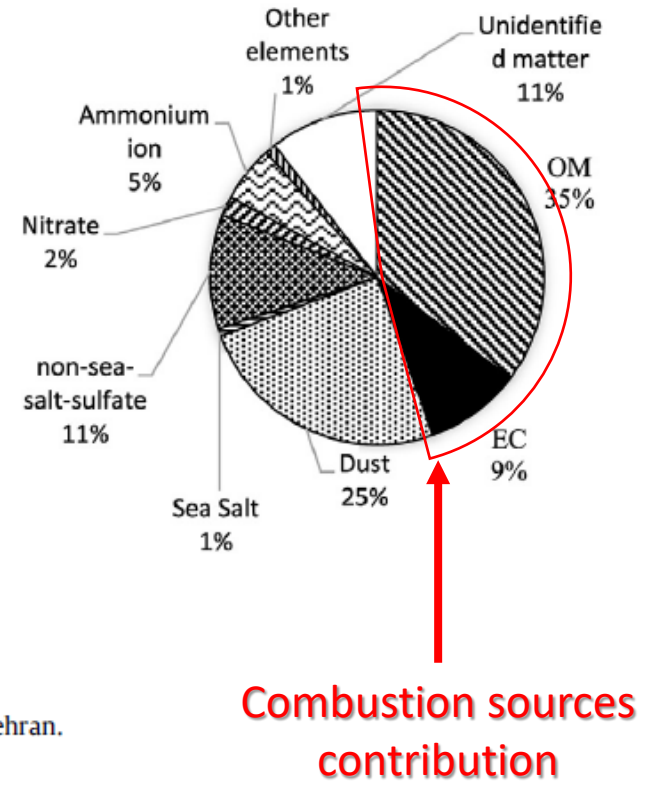
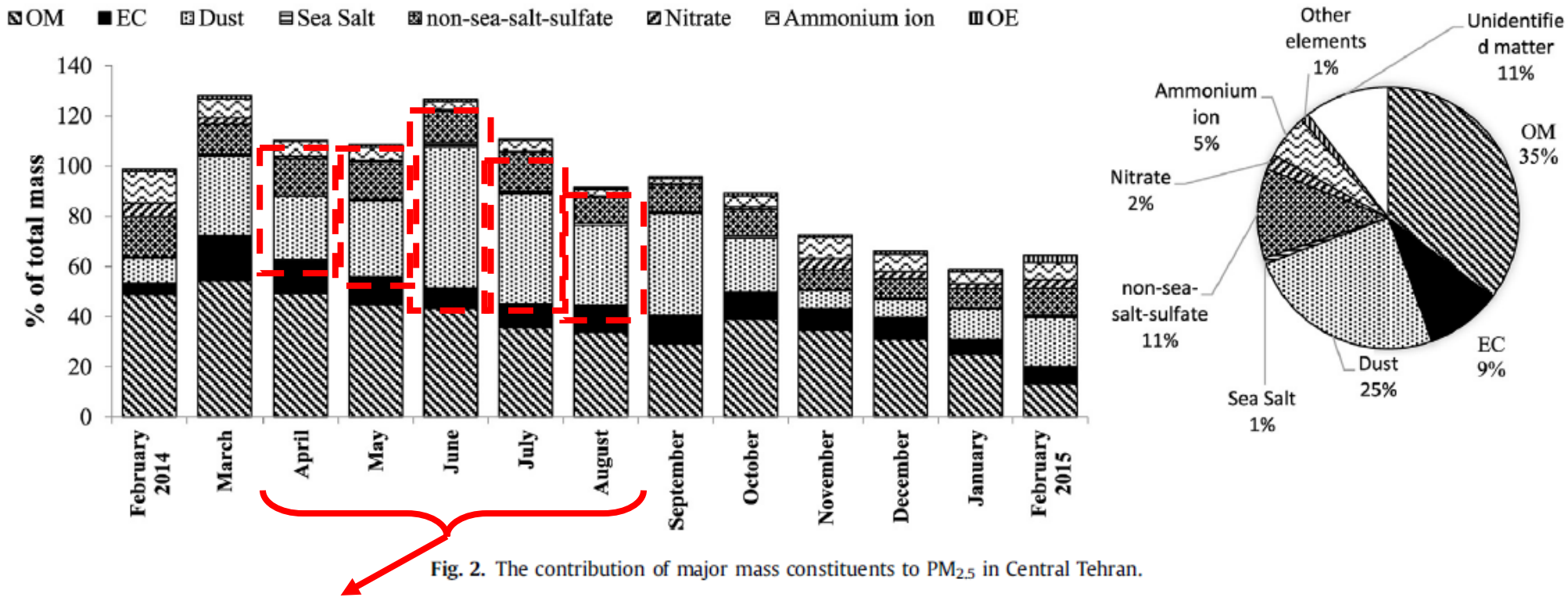


Combustion sources contribution

PM2.5 source apportionment study (University of Wisconsin)



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Spring and summer dust

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PM2.5 source apportionment study (University of Wisconsin)

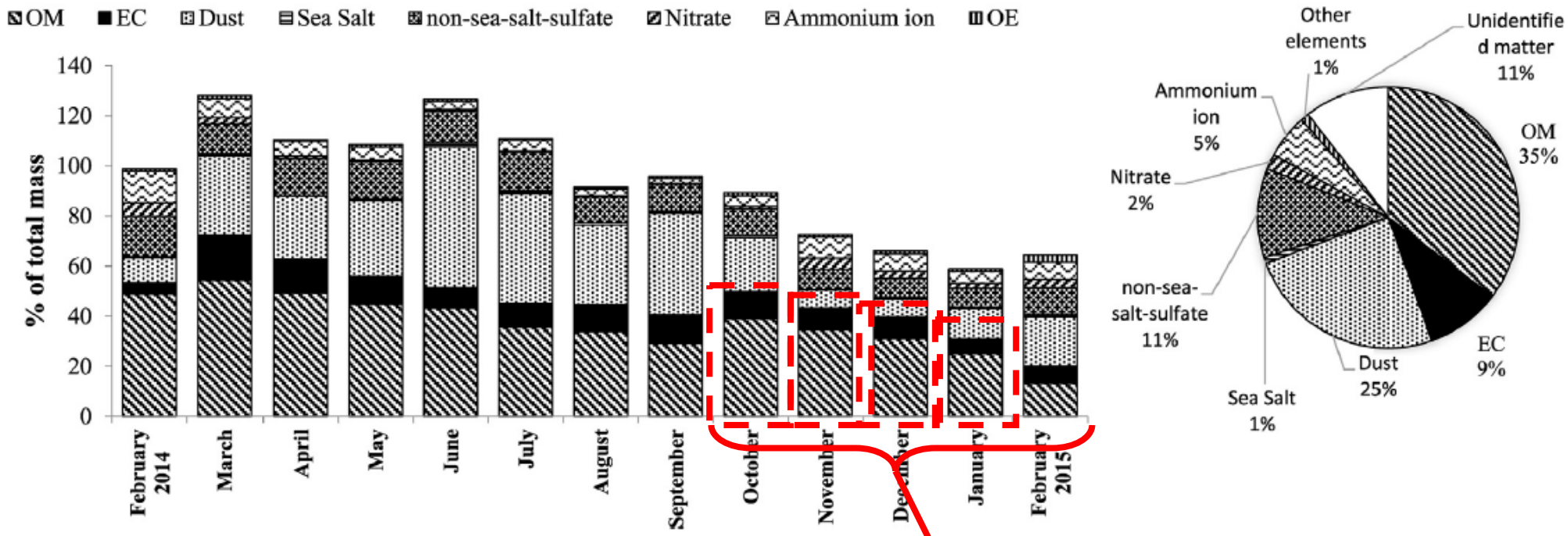

Fig. 2. The contribution of major mass constituents to $PM_{2.5}$ in Central Tehran.

Fall and winter OM coming from combustion and intensified by inversion periods

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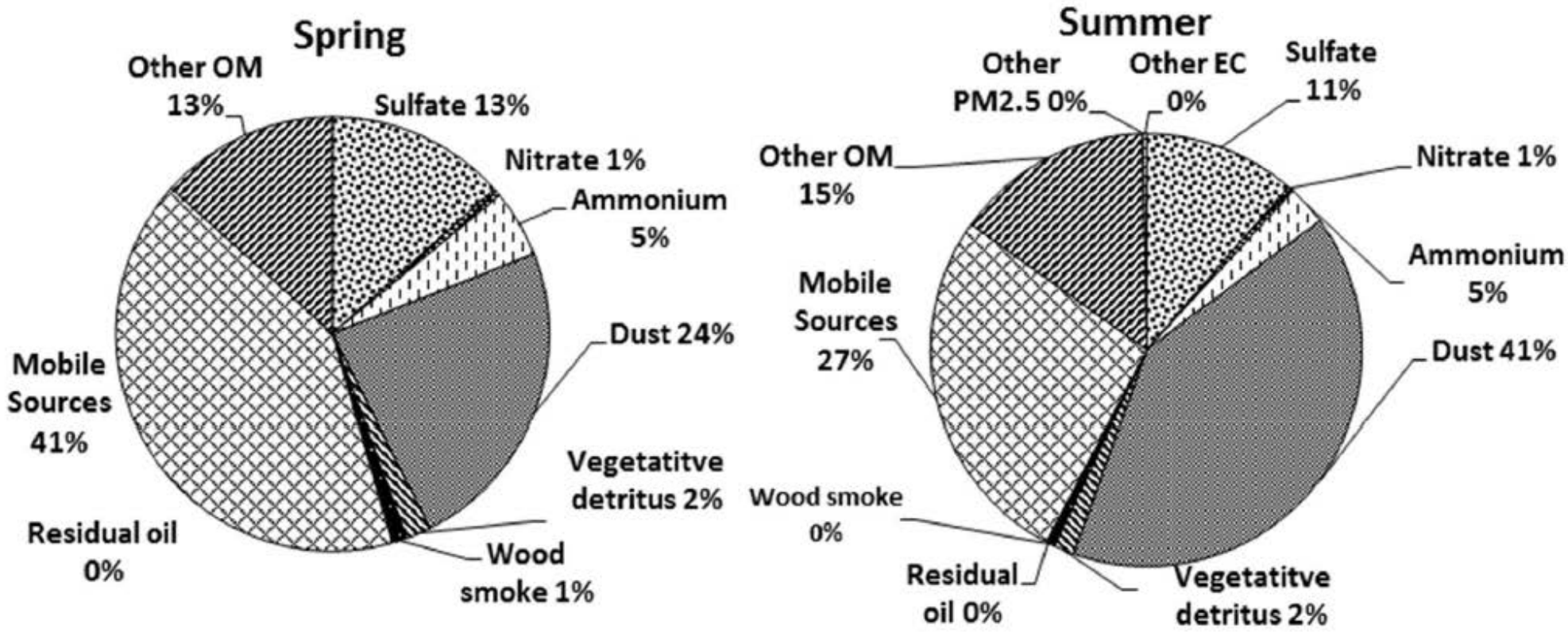
Results of CMB receptor modeling based on PM2.5 chemical analyses

M. Arhami et. al., Environmental Pollution 239 (2018) 69-81



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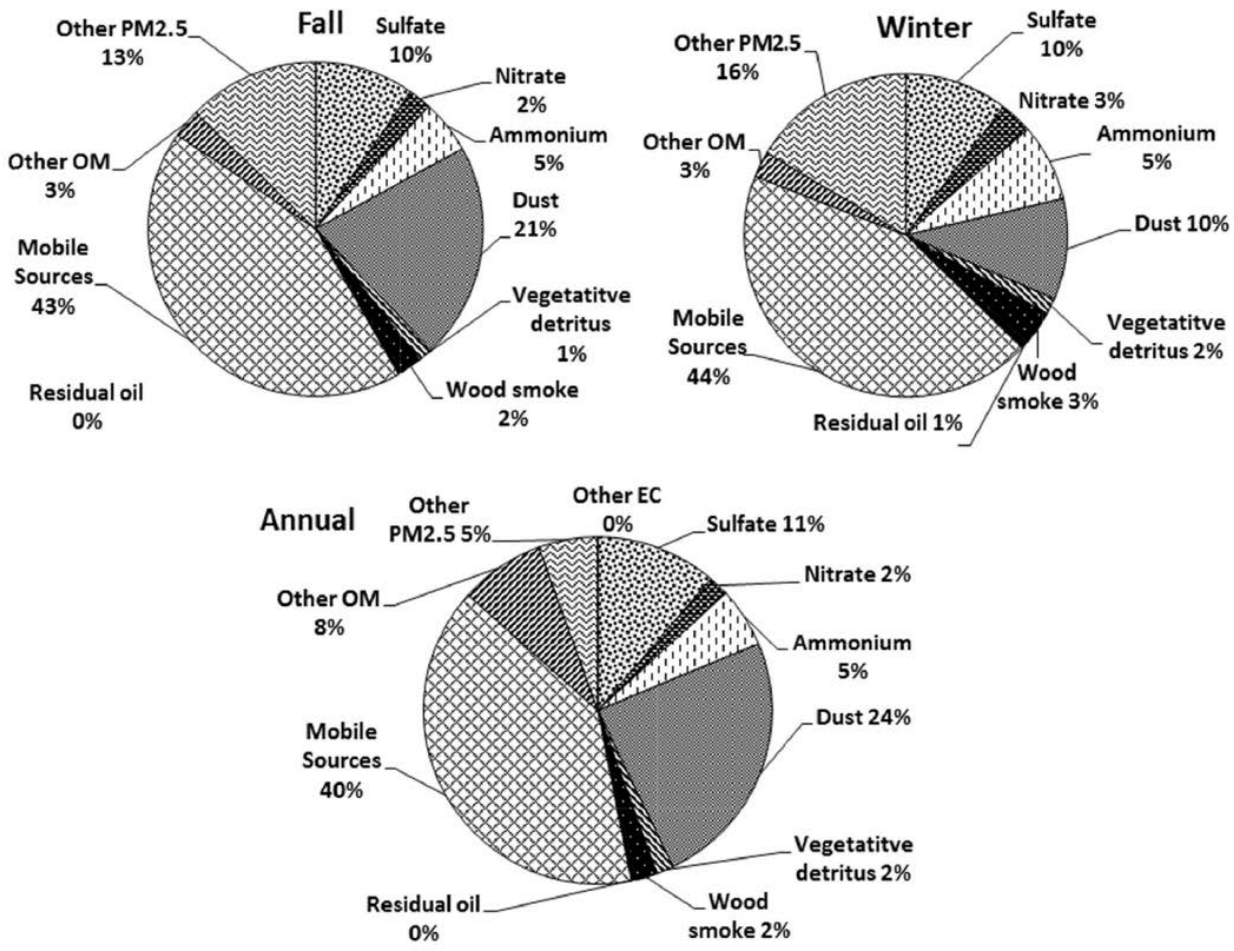


Fig. 8. Source apportionment to $PM_{2.5}$ in Tehran (% contribution).

Annual mean of benzene and o-xylene (Swiss TPH)
(180 sampling site using passive samplers in 1-year period)

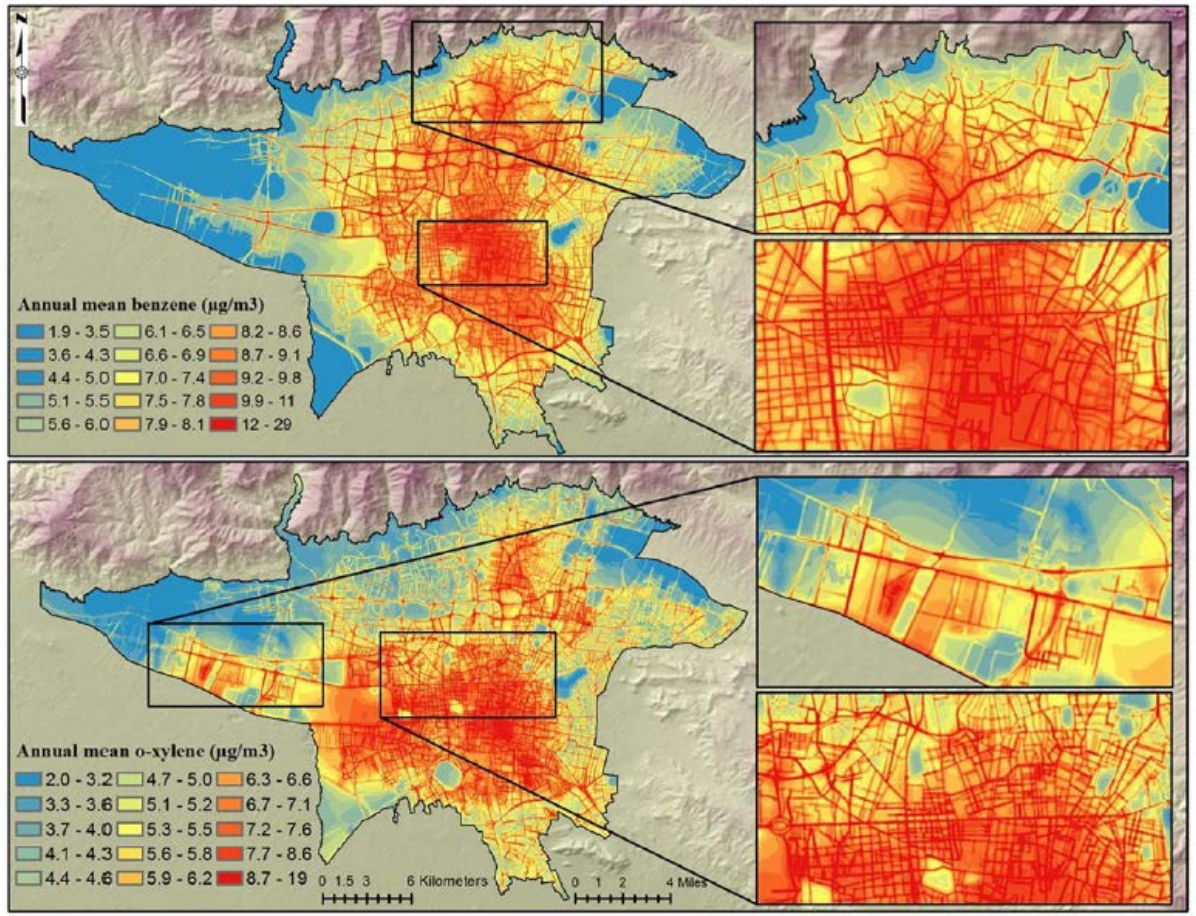


Figure 2. Predicted annual mean concentrations of benzene and *o*-xylene in Tehran SEPEHR, Tehran, Iran. The insets are categorized by quantiles. For ease of interpretation, the first three classes of benzene are shown by blue color indicating areas where annual mean benzene was below 5 $\mu g/m^3$ (an air quality standard used in some countries). Although both pollutants were mainly driven by traffic-related variables, industrial areas, mainly in western part of the city, explained variability of *o*-xylene (top right panel of the *o*-xylene). See Figures S1 and S2 for map of all pollutants. The spatial resolution of maps is 5×5 m^2.

DOI: 10.1021/acs.est.7b02238
Environ. Sci. Technol. 2017, 51, 8481–8490

Annual mean of NO, NO2, and NOx (Swiss TPH)

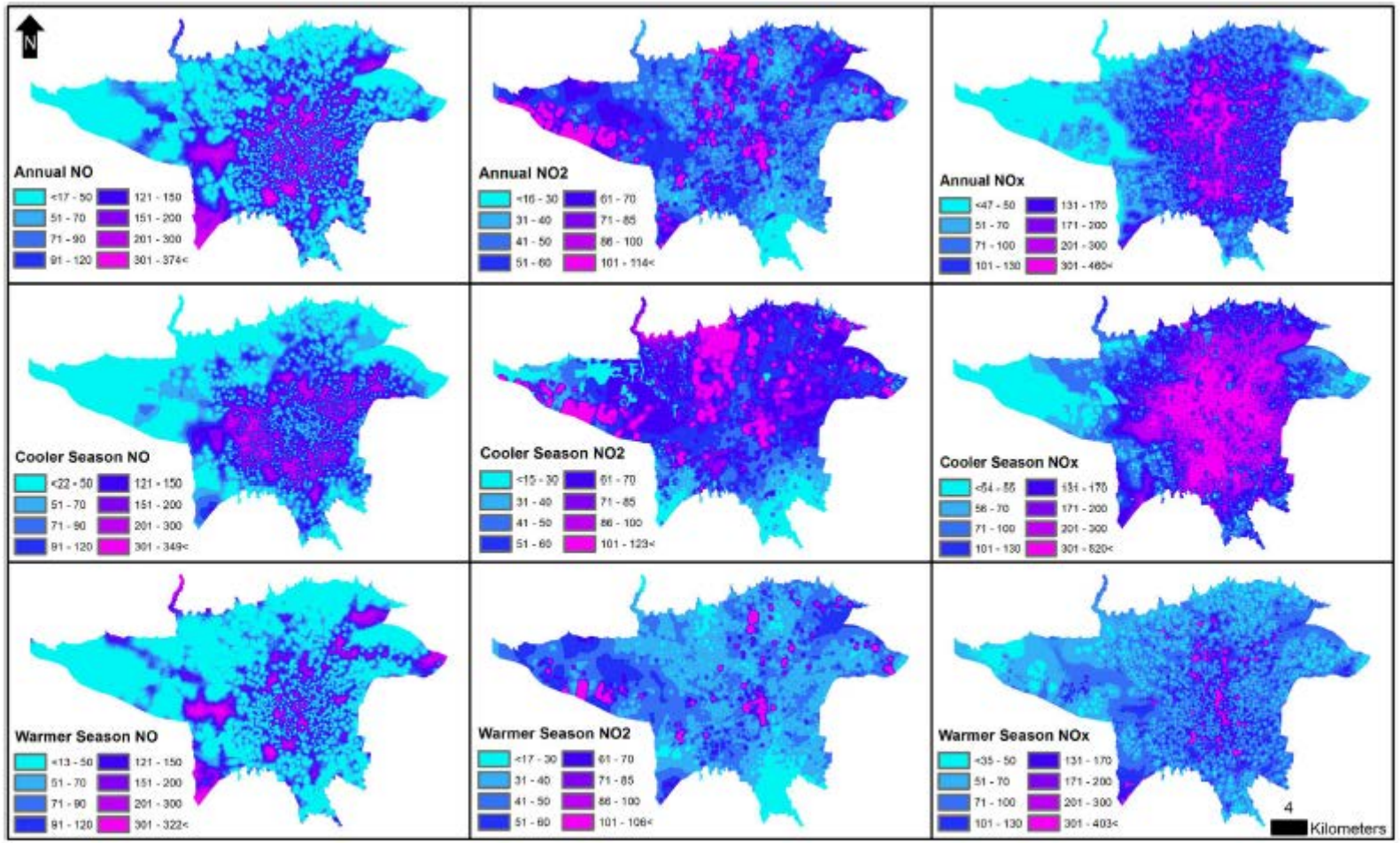
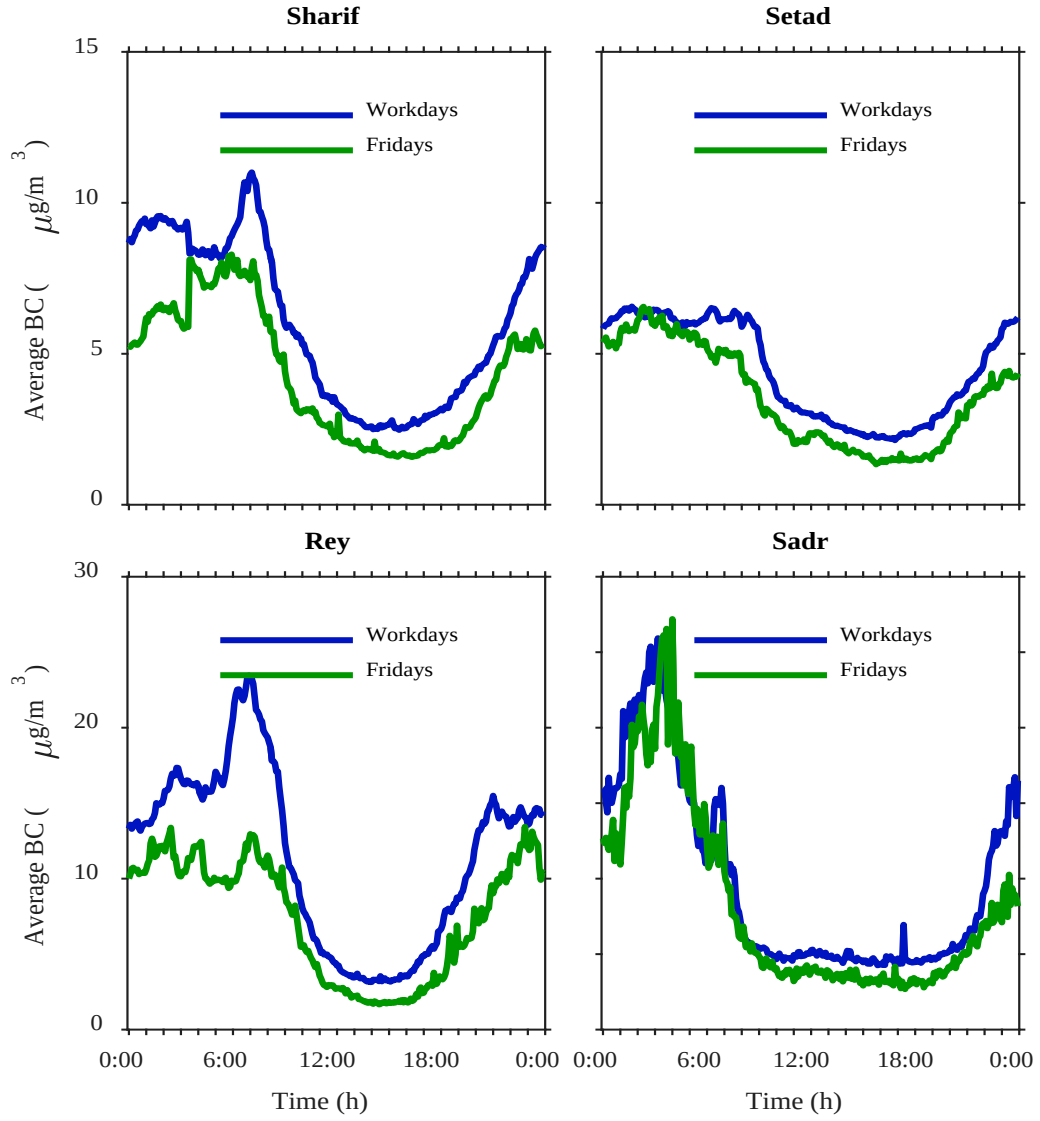


Figure 3. Estimated annual, cooler and warmer seasons NO, NO_2 and NO_X concentrations (ppb) from the final land use regression models in Tehran, Iran, 2010. The *prediction resolution* is 5 × 5 meters. The figure is generated using ESRI's ArcGIS 10.2.1 for Desktop (ESRI, Redlands, CA, USA, http://www.esri.com/).

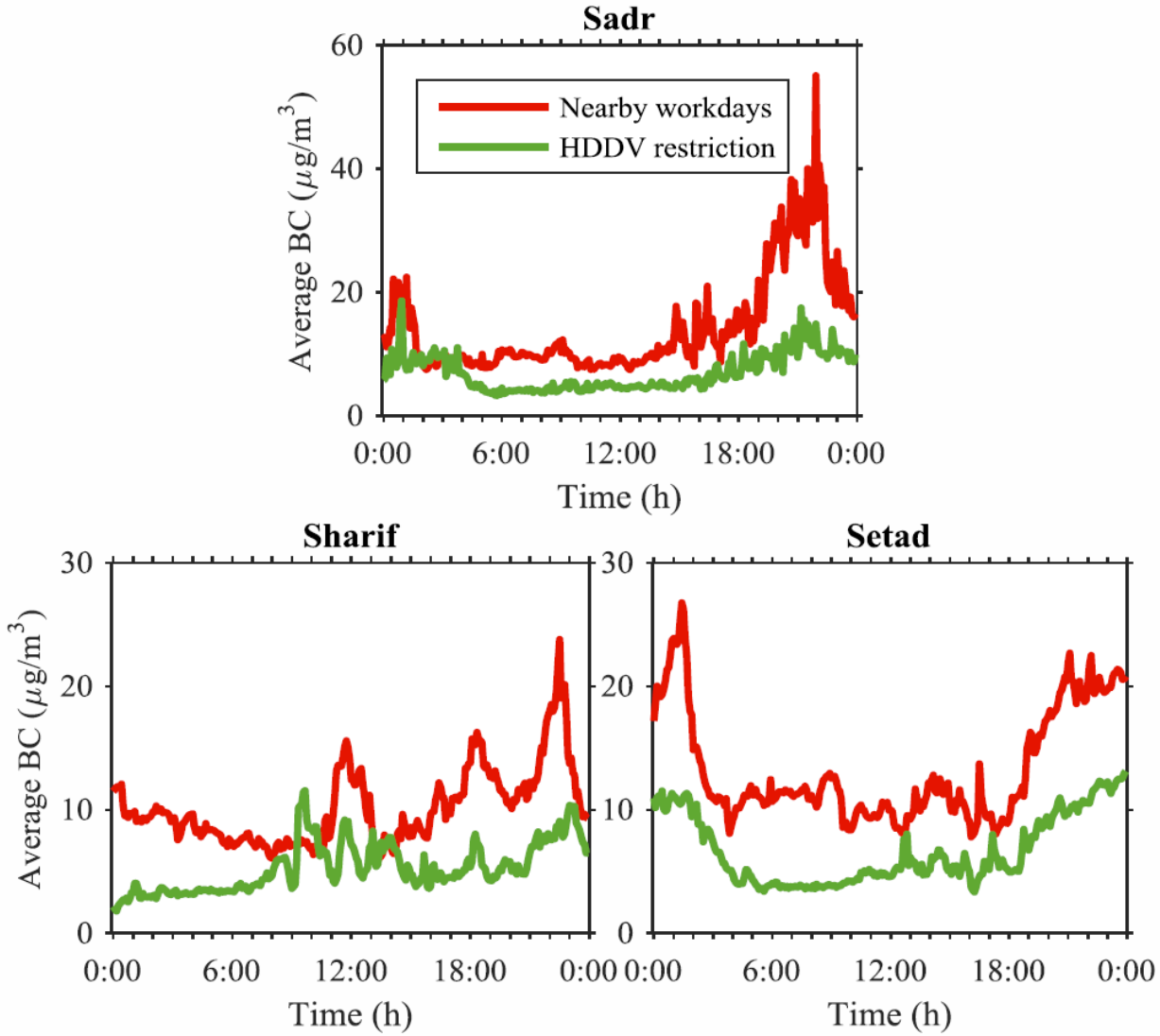
SCIENTIFIC REPORTS | 6:32970 | DOI: 10.1038/srep32970

BC measurement using online aethalometers (PSI, Switzerland)



Effects of restricting over-night truck traffic on BC concentration

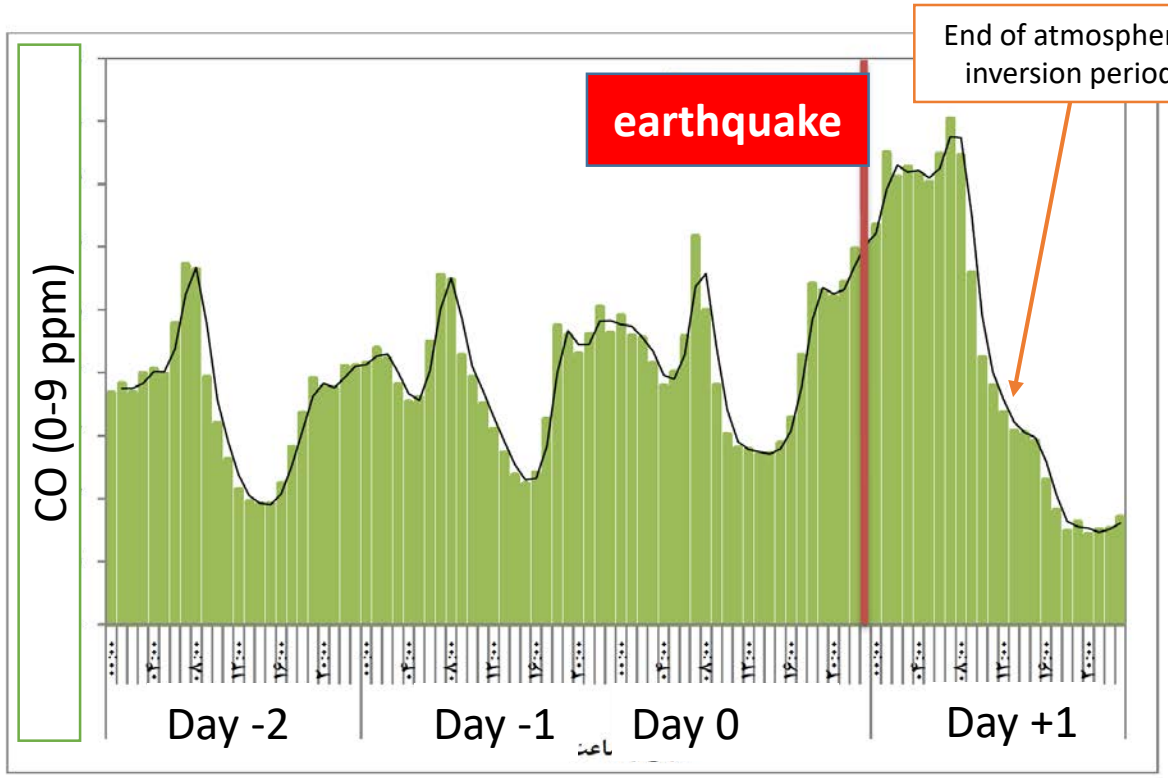
(Dec 12-15, 2017 – an episode of air pollution that resulted in city-wide school shut-down and traffic restrictions)

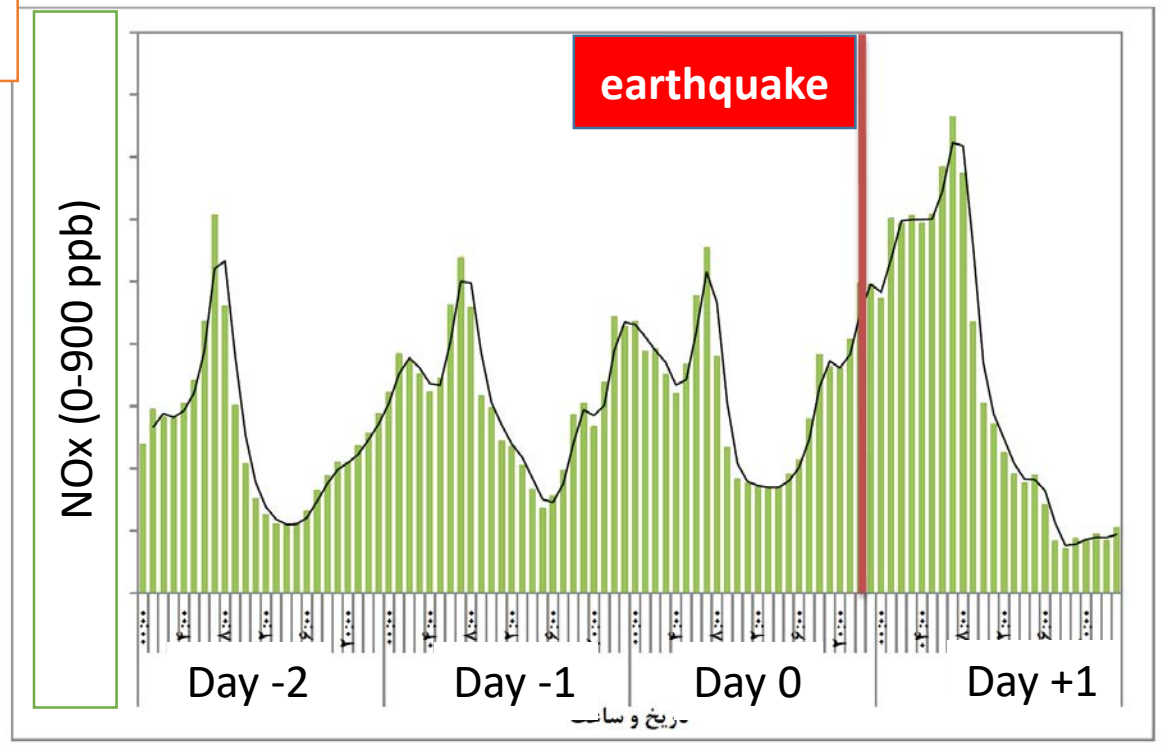


An interesting observation: Tehran earthquake

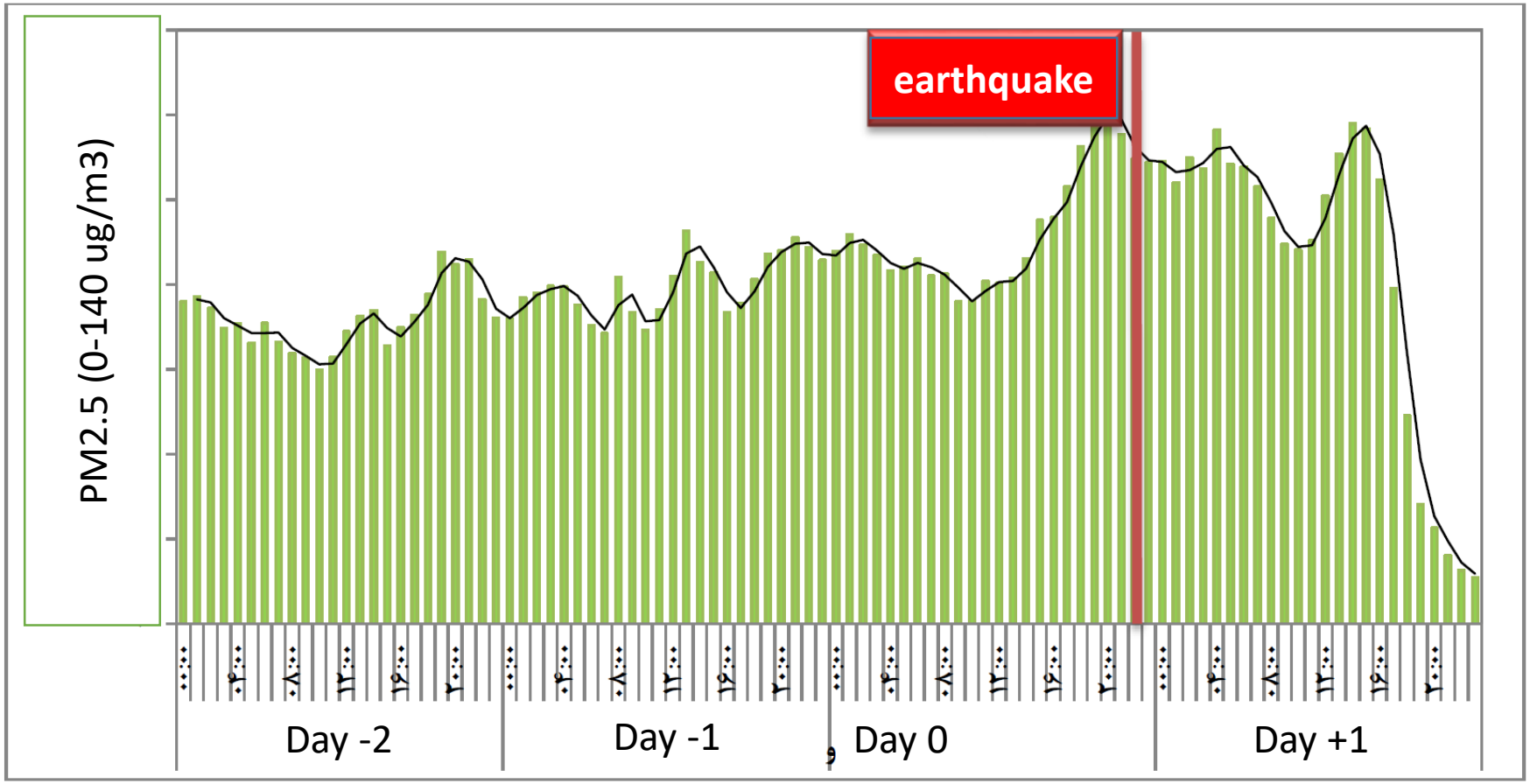
- On 11:57 PM of Dec 12, 2017 an earthquake with the magnitude of 5.2 hit Tehran.
- It was a cold night after 3 days of thermal inversion (a long episode).
- Tehran citizen stayed out of their home for whole night with their gasoline LDVs idling.

Idling of large number of LDVs over-night in Tehran increased average CO and NOx concentrations





Almost no effect on PM2.5 as the result of idling over-night (cold night, no-sunlight)



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National level-activities

- The very first initiation of filters in Iran : 2014
- In 3 years:
  - There is national legislation for all diesel vehicles → Euro IV+DPF OR Euro V EEV are current national standards
    - Euro V EEV was lobbies afterward into the legislation by the forces of European manufacturers like Daimler and MAN
    - Before licensing every Euro V EEV vehicle, an equal (by power) old vehicle needs to be scrapped. This increases the price of Euro V EEV vehicles compared to that of Euro IV+ DPF
  - Approx. 5000 VERT-approved filters and another 5000 filters have been already installed in the market (newfit, option-fit, and retrofit)
- City of Tehran has approved soot-purchasing scheme (contractors are paid more if install filters)
- Issues at hand:
  - I/M program, instrument, test procedures
  - Enforcement (proper TA and COP)
  - Tampering and cheating
  - Diesel fuel quality (<50 ppm sulfur diesel fuel became available nation-wide)

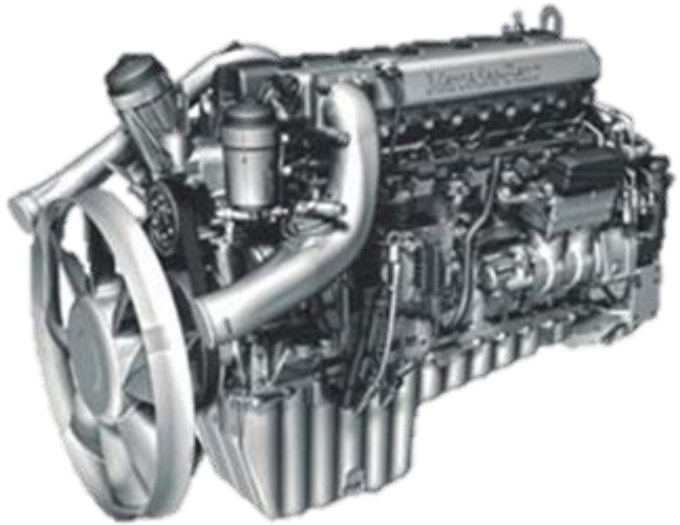
Background DPF retrofit activities

- PEMS Experience:
    - 5 Years of Experience In RDE Measurements of gasoline and CNG LDVs

- DPFs Feasibility Study Project:
    - Engine dynamometer tests (2014)
    - Different DPF technologies evaluated (2014-2016)
    - Pilot installation (2015-2017)
    - Periodical stationary UFP emission measurements on urban buses (2015- now)
    - RDE Measurements

Engine dyno tests and pilot runs

Engine Dynamometer Tests



- Test procedure: VFT 1
- Tested engine: Daimler OM 457
- Tested fuel: LSD (50 ppm), MSD (229 ppm), HSD (7000 ppm)
- Number of tests: More Than 7 DPFs with various sulfur-contained fuels
- Evaluation criteria:
  - DPF performance (PM & PN efficiency, gaseous emission)
  - Safety issues
  - Regeneration quality and soot capacity
  - Sulfur tolerances

Engine Tests’ Outcome

- Full Report of Engine Tests’ Results
- Determination of Candidate DPFs for Field Tests
- Papers and presentations
  - ETH combustion generated conference
    - http://www.nanoparticles.ch/archive/2017_Hosseini_PR.pdf
    - http://www.nanoparticles.ch/archive/2016_Hosseini_PR.pdf
    - http://www.nanoparticles.ch/2014_ETH-NPC-18/4a-1_Hosseini.pdf
  - Doozandegan, Hosseini, Ehteram, Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering, DOI: 10.1177/0954407017701283, 2017

Original Article

Institution of MECHANICAL ENGINEERS

Solid nanoparticle and gaseous emissions of a diesel engine with a diesel particulate filter and use of a high-sulphur diesel fuel and a medium-sulphur diesel fuel

Mahdi Doozandegan[1], Vahid Hosseini[1] and Mohammad Ali Ehteram[2]

Abstract
High-sulphur and medium-sulphur diesel fuels are still used in several countries. Although diesel particulate filter technology for on-road diesel engines has existed since 1989, the availability of high-sulphur and medium-sulphur diesel fuels in the market causes delays in the use of catalysed filter technologies. However, the situation in places such as Tehran is considered unhealthy because of particles and black carbon, and full distribution of ultra-low-sulphur diesel is awaited eagerly. The purpose of this study is to investigate the effect of the sulphur content in fuels on the gaseous and solid exhaust emissions of a 220 kW Euro II engine equipped with a sintered metal active–passive filter, focusing on the regeneration phenomenon. The results show that the efficiency for filtering the maximum number of particles was 99.9% and that the average was above 99% for steady-state operating conditions for both high-sulphur diesel (7700 ppm) and medium-sulphur diesel (229 ppm). The removal efficiency of the particle mass was low in the case of high-sulphur diesel owing to the sulphate condensate collection effect as the result of using a non-heated sample line. During regeneration, the number of particles increased in comparison with that in the filtration phase but the total number of emitted particles was less than the engine baseline value. The results for both fuels were the same, and the only measurable difference was the high sulphur dioxide production in the high-sulphur diesel during regeneration. This study demonstrates the potential of this type of filter technology for the effective removal of solid particles independent of the sulphur content of the fuel. With the exception of the decrease in the removal efficiency of the particle mass and the high sulphur dioxide production, no other notable difference was observed to be caused by the change in the sulphur content of the diesel fuel.

Keywords
Nanoparticle emissions, active regeneration, sulphur, diesel, diesel particulate filter

Date received: 3 July 2016; accepted: 20 February 2017

Introduction

Diesel engines are generally known for their excellent durability, reliability and fuel efficiency which contributes to a lower carbon dioxide (CO_2) footprint. Also, their operation concepts result in low hydrocarbon (HC) emissions and low carbon monoxide (CO) emissions. Despite all these positive qualities, the particulate matter (PM) emissions are a serious problem for diesel engines.[1] Health effect issues and growing concern regarding the PM emissions are resulting in more restrictive emissions standards for diesel engines.[1,2] Hence, diesel particulate filters (DPFs), which were known as traps in the mid-1970s to late 1970s, have been developed for diesel applications. Many data on DPF technologies have already been published in the literature.[3]

The operation principle of closed DPF systems is based on the deposition of airborne particles on a porous media wall. To avoid blockage of the DPF, which results in an excessive exhaust back pressure or

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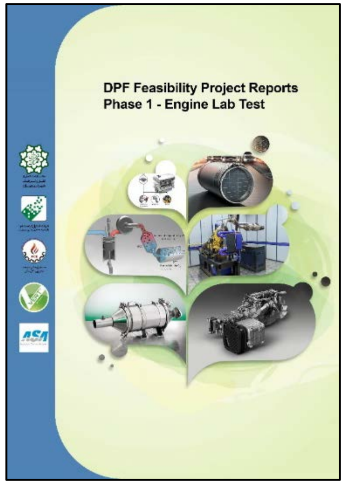
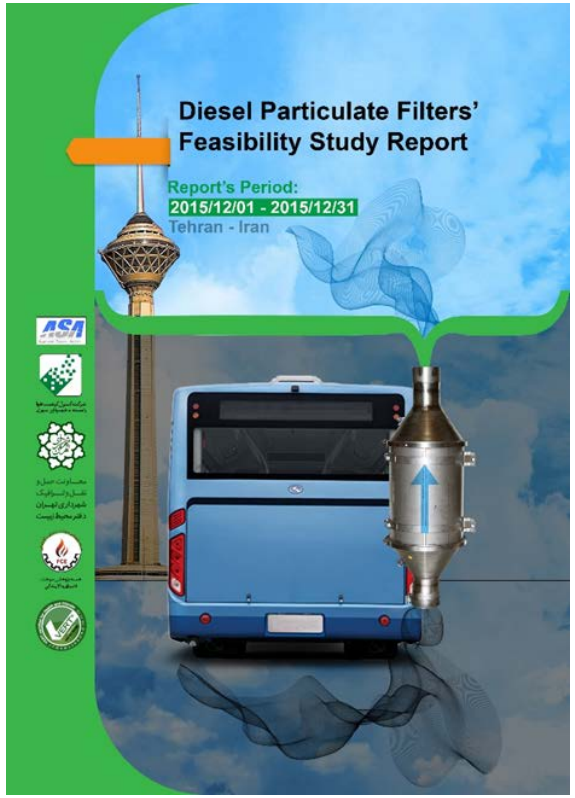


Field Tests

- Target vehicles: Tehran BRTs
- Tested engine: MAN
- Tested fuel: Mostly LSD (50 ppm) and Occasionally MSD (229 ppm)
- Test procedure: 50,000 km at low and high exhaust temperature routes
- Number of Installed DPFs: 14 filters with various technologies (FBC, CDPF, etc.)
- Evaluation Criteria:
  - Durability
  - Appropriate Regeneration Regime
  - Reasonable Cleaning Intervals

Results of early first tests

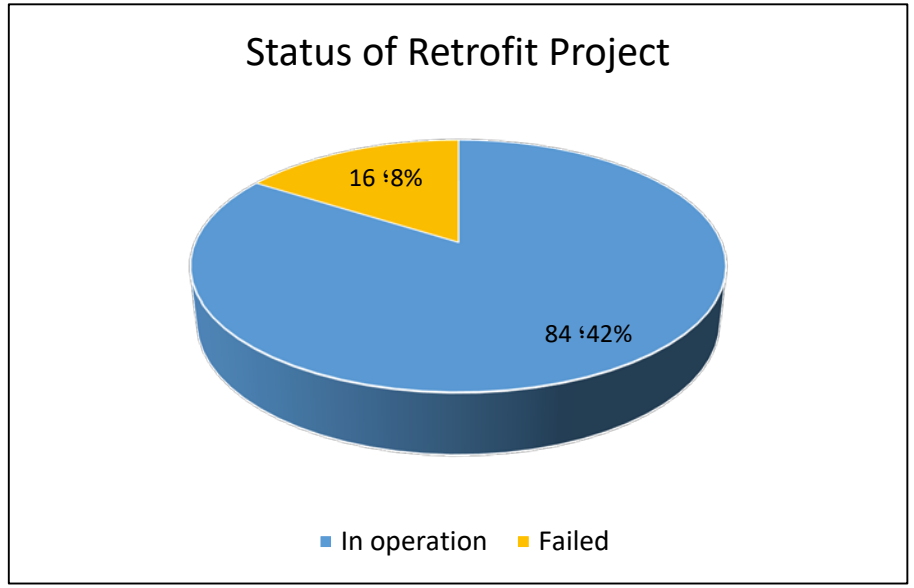
- Monthly reports are available
- Filters are monitored using an smart phone application by VERT Iran’s office(FilterNama)
- Determination of candidate DPFs for retrofit projects
  - Total Installed DPFs: **14 pieces**
  - 6 technologies were approved for low temperature routes
  - 3 technologies were approved for high temperature lines
  - 3 technologies were rejected (CRTs)
  - 3 technologies still under consideration (CDPFs)
  - Total mileages: **more than 1,000,000 km.**

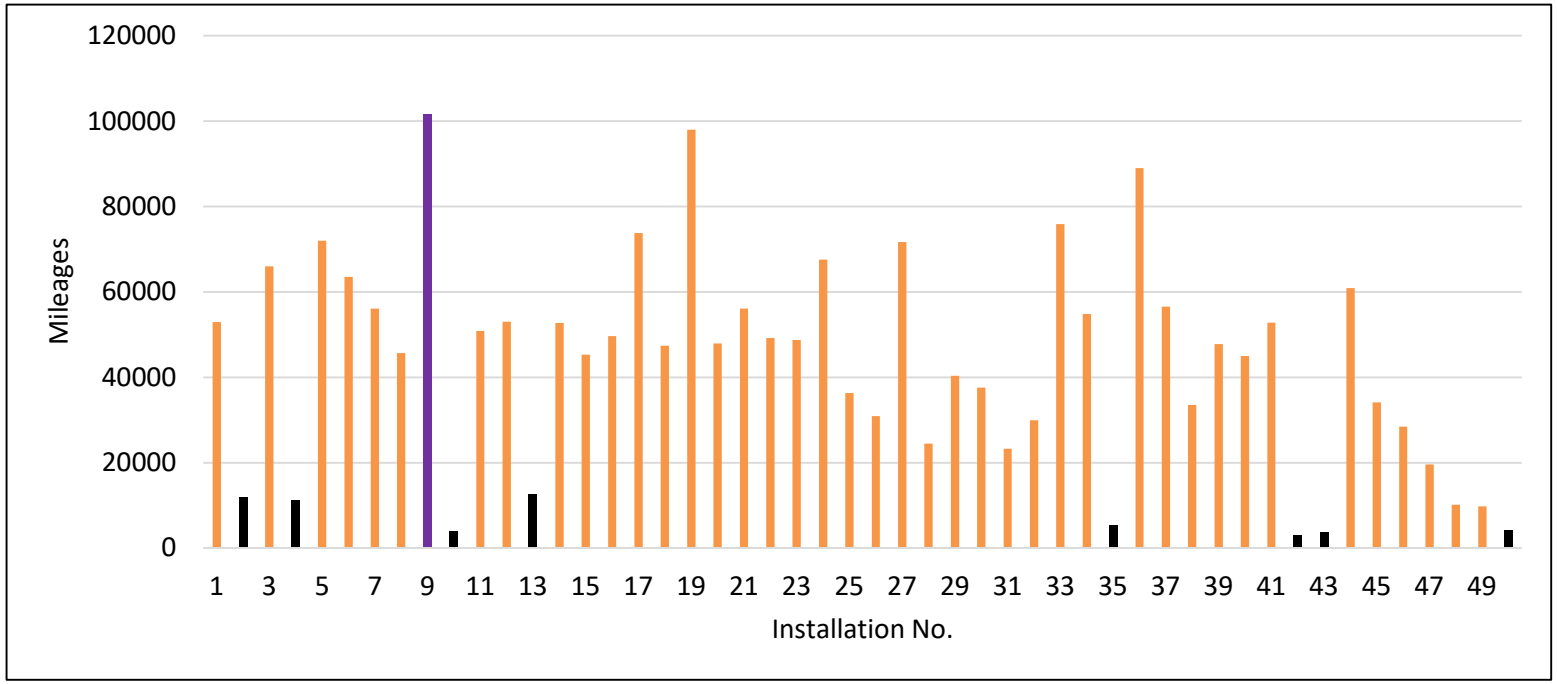


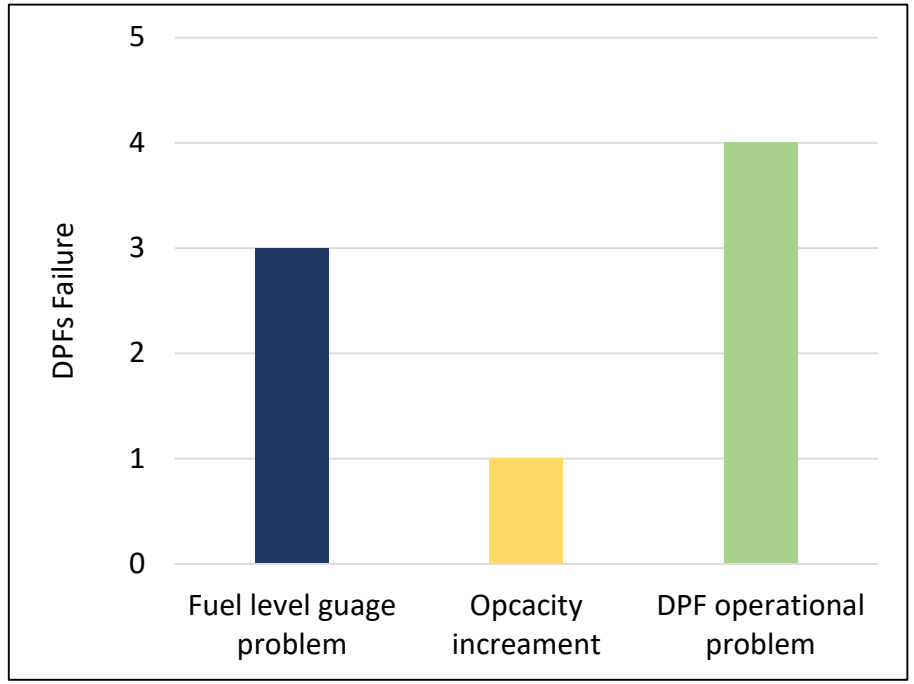
Retrofit project for city buses

DPF Retrofit Projects

- Target vehicles: Tehran city buses
- Installed DPFs: 50
- Total mileages: 2,251,796 km







Tehran DPF Retrofit Project Status

- Pilot Tests are Running Since 2014 (10 buses, 6 technologies)
- 50+ DPF Retrofitted Buses

awareness and outreach

Pilot tests, local conditions

new products are coming

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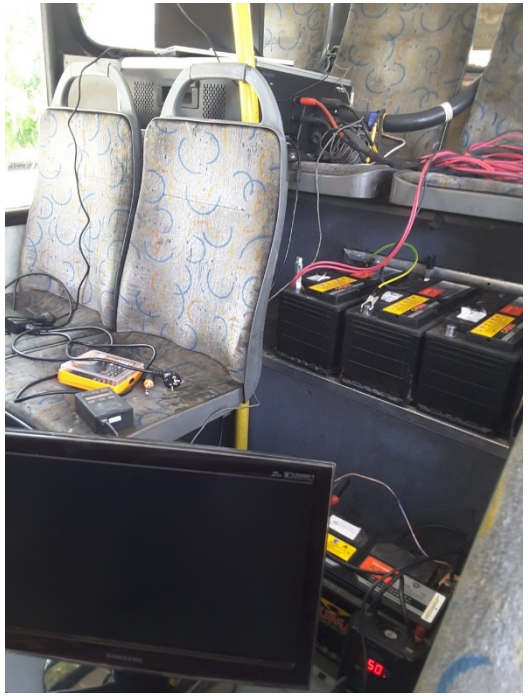
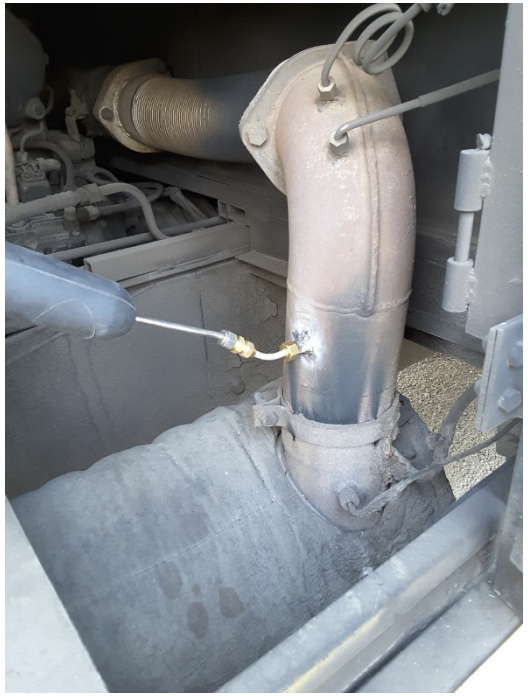
- Background of Tehran air pollution,
  - **Scientific evidences that led to big shift in policies, mobile source contribution**
- Background and history of national activities
- First RDE study of a DPF-retrofit bus using PEMS
- Investigating effects of elevation on diesel emission
- Conclusions

Filter evaluation under RDE conditions using PEMS

Test Vehicle and filter

Engine Specification	
Manufacturer	Mercedes - Benz
Engine Model	OM 457
Emission Standard	EURO II
Configuration	Inline 6
Displacement	11967 cc
Cylinder Bore	128 mm
Piston Stroke	155 mm
Compression Ratio	18.5:1
Rated Power	260 kW @ 2000 RPM
Rated Torque	1600 N.m @ 1100 RPM
Filter	Sintered metal filter, FBC, electric heater





Instruments

AXION PEMS

matter aerosol
a testo company

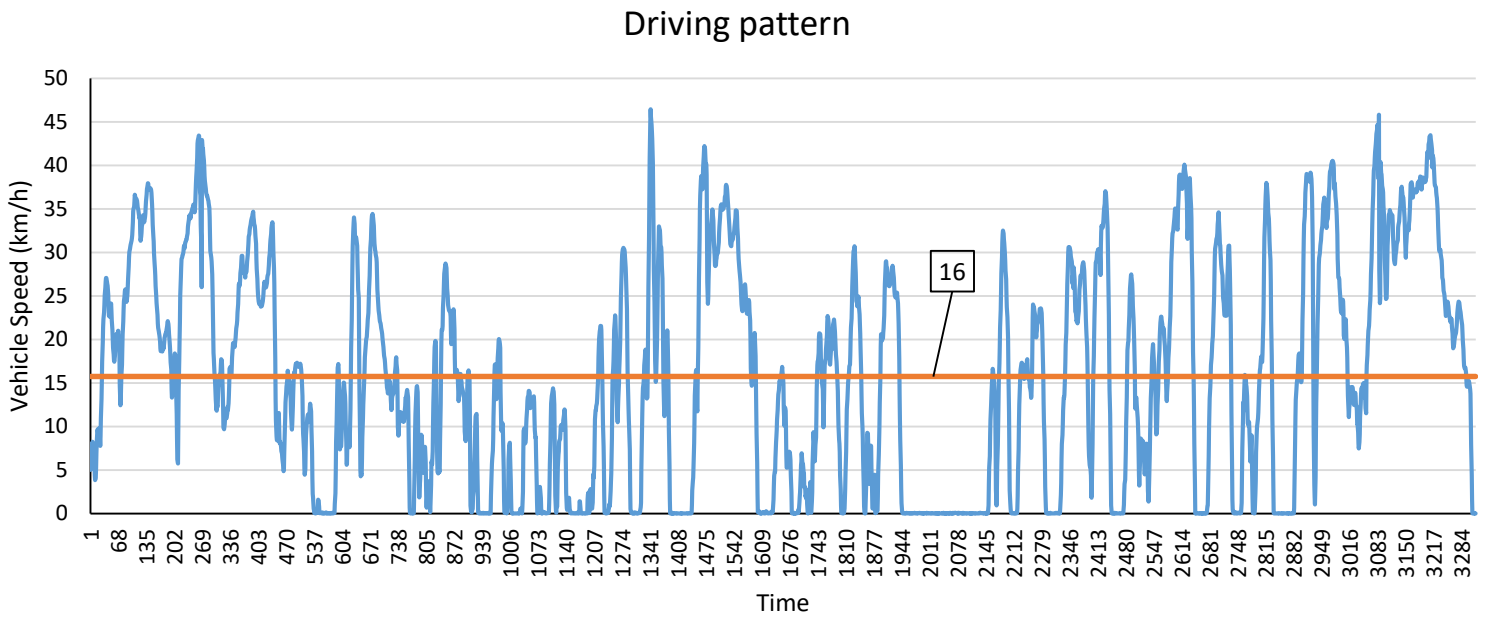
Testo NanoMet3

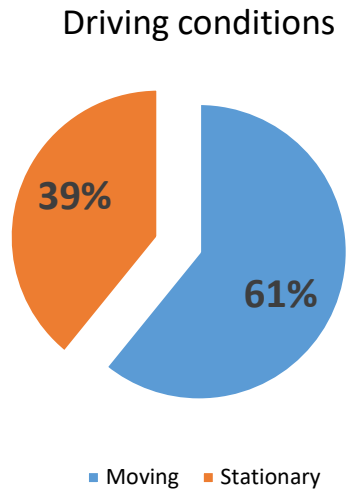
Test Route #1: west-east direction

Route Detail:
Grade ≈ 0%
Distance = 15.8 km
Traffic Jam = Medium - Heavy

Route #1: Urban Street - Flat

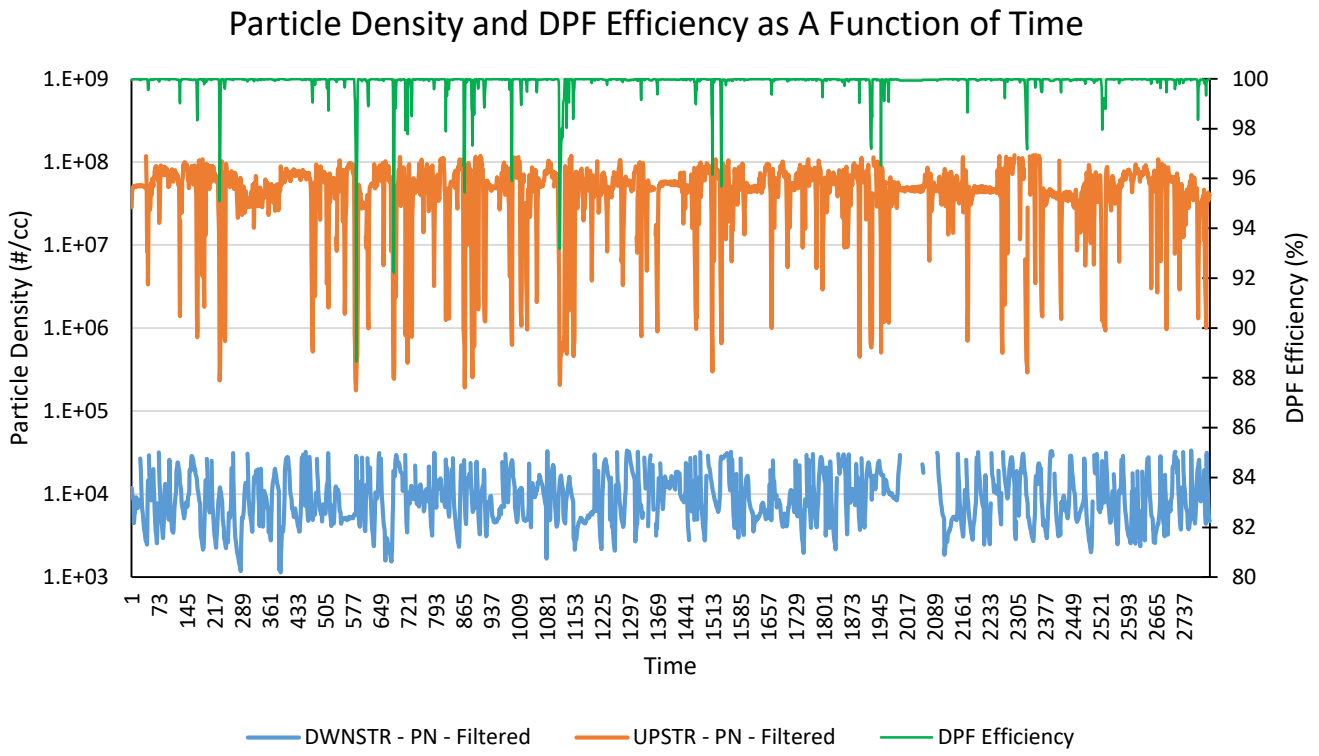
Route #1 : Flat Urban Street

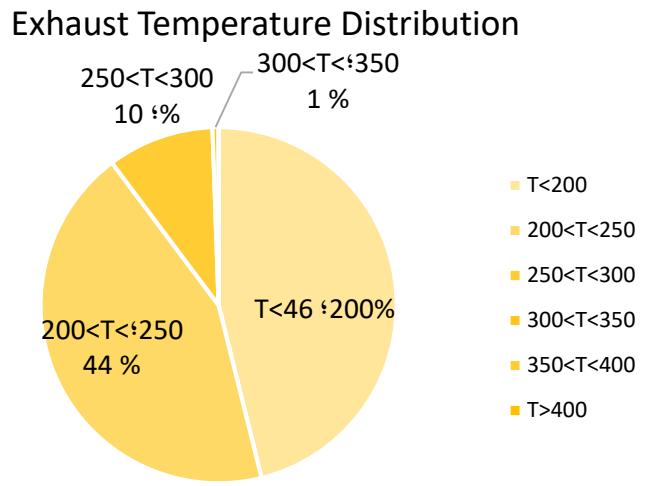




Route #1 – particle number count and filter efficiency

Route #1 : Flat Urban Street

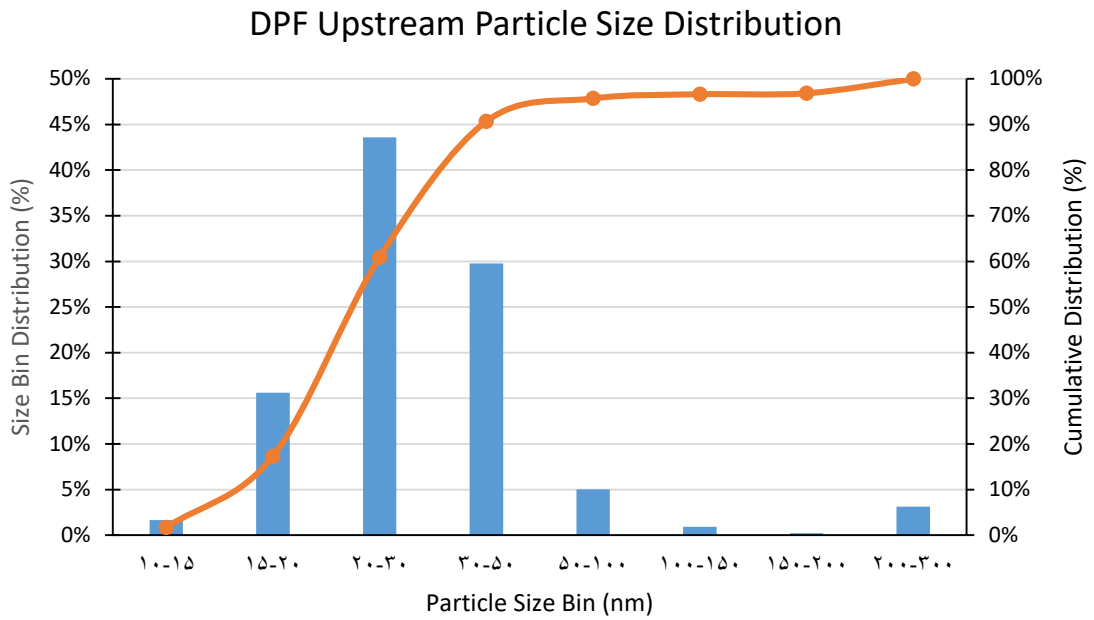


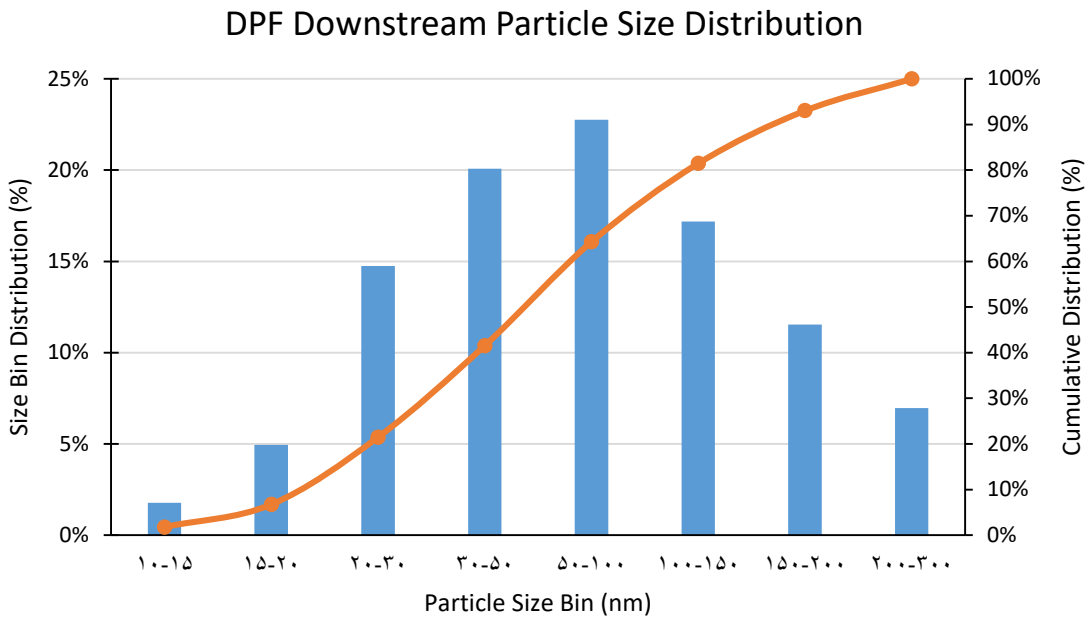


- Average Emission Factor of PM was 1.07×10^{15} [#/km] and 1.68×10^{11} [#/km] for before and after DPF, respectively.
- Average filtration efficiency by number 99.98%.

Route #1 – particle size distribution

Route #1 : Flat Urban Street

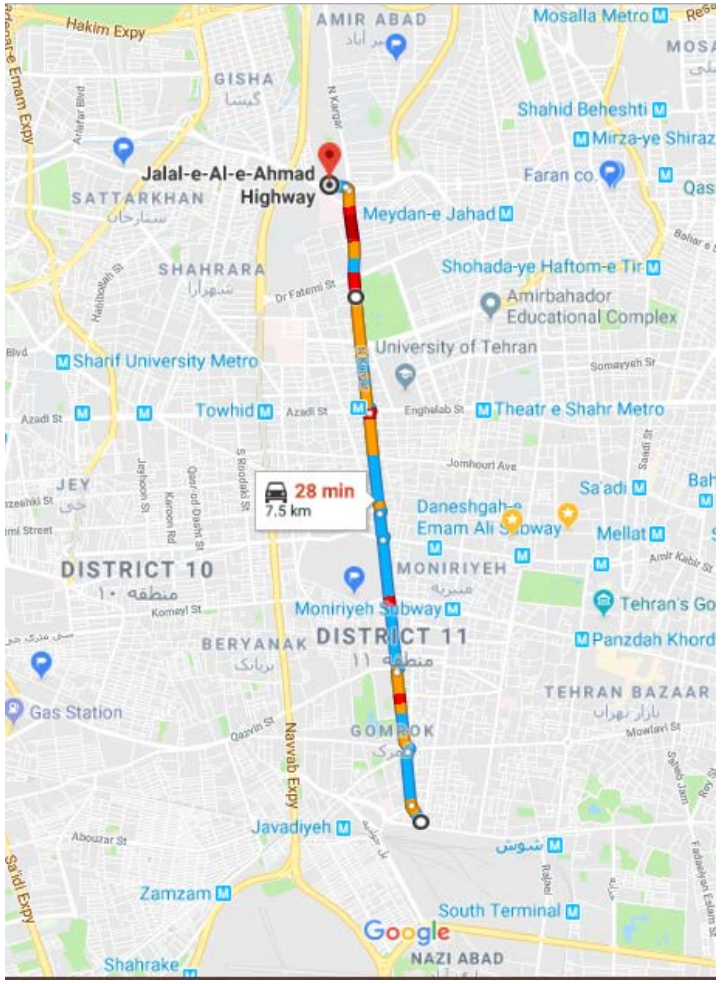




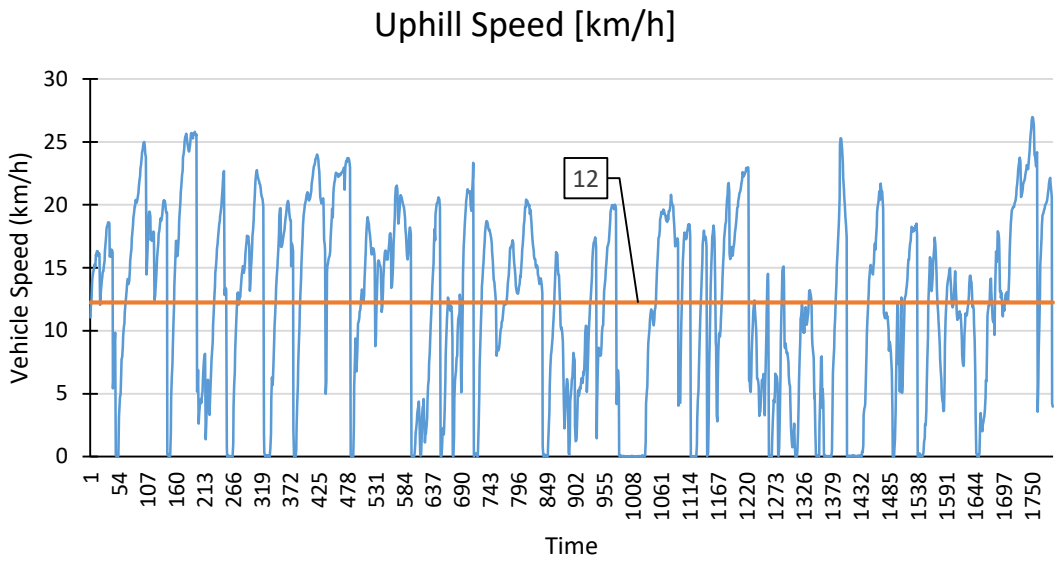
- After filter, more uniform particle size distribution was observed

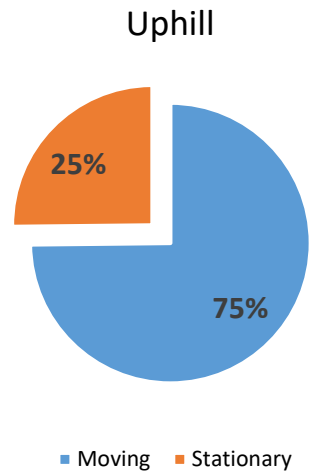
Test Route #2: south-north direction

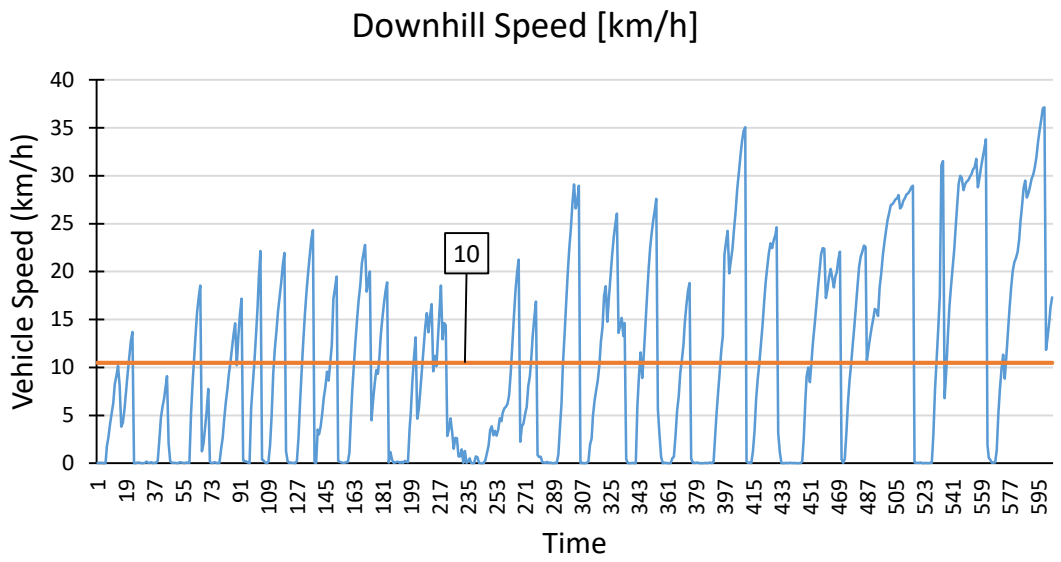
Route Detail:
Grade ≈ 3%
Distance = 15 km
Traffic Jam = Medium - Heavy

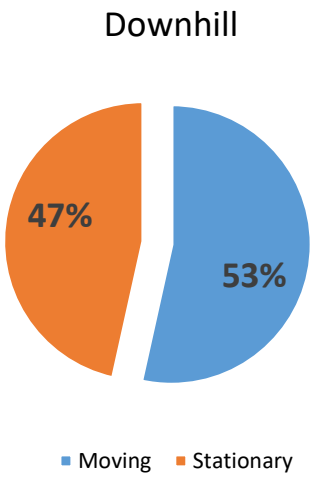


Route #2: Urban Street – 3% Average Grade


Uphill Speed [km/h]
Vehicle Speed (km/h)
Time
12
0
5
10
15
20
25
30
1
54
107
160
213
266
319
372
425
478
531
584
637
690
743
796
849
902
955
1008
1061
1114
1167
1220
1273
1326
1379
1432
1485
1538
1591
1644
1697
1750

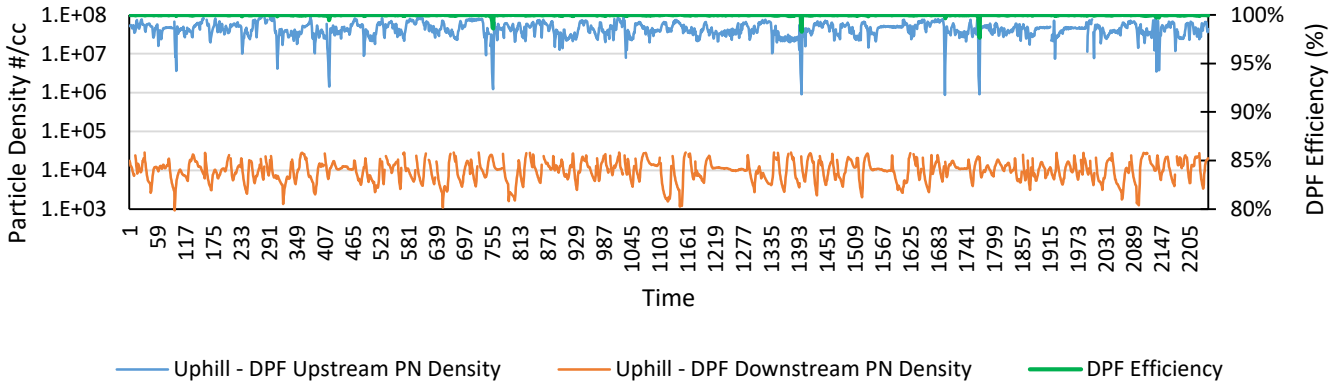

Uphill
25%
75%
Moving
Stationary


Downhill Speed [km/h]
Vehicle Speed (km/h)
Time
10
0
5
10
15
20
25
30
35
40
1
19
37
55
73
91
109
127
145
163
181
199
217
235
253
271
289
307
325
343
361
379
397
415
433
451
469
487
505
523
541
559
577
595

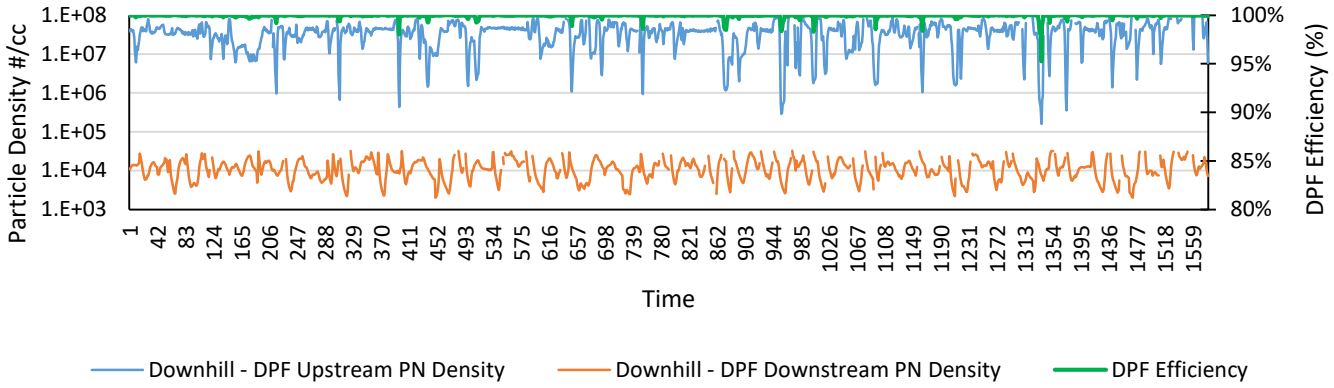

Downhill
47%
53%
Moving
Stationary

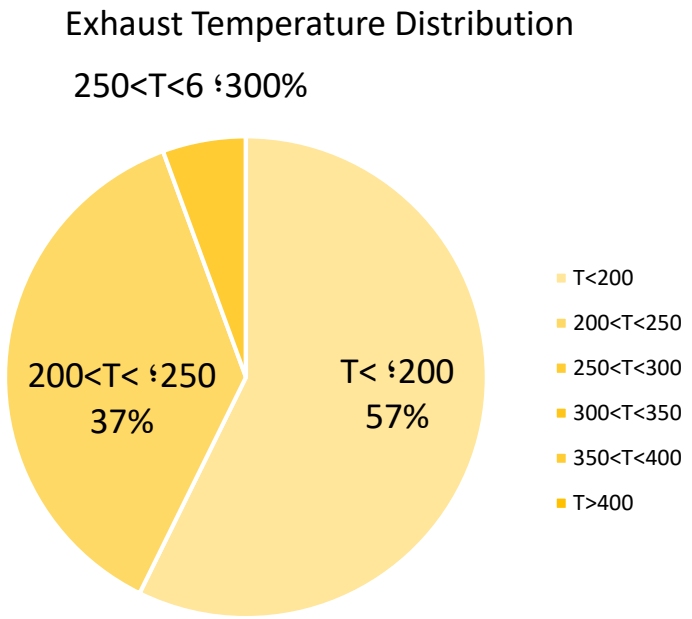
Route #2 – DPF Efficiency

Route #2 : Urban Uphill



Route #2 : Urban Downhill

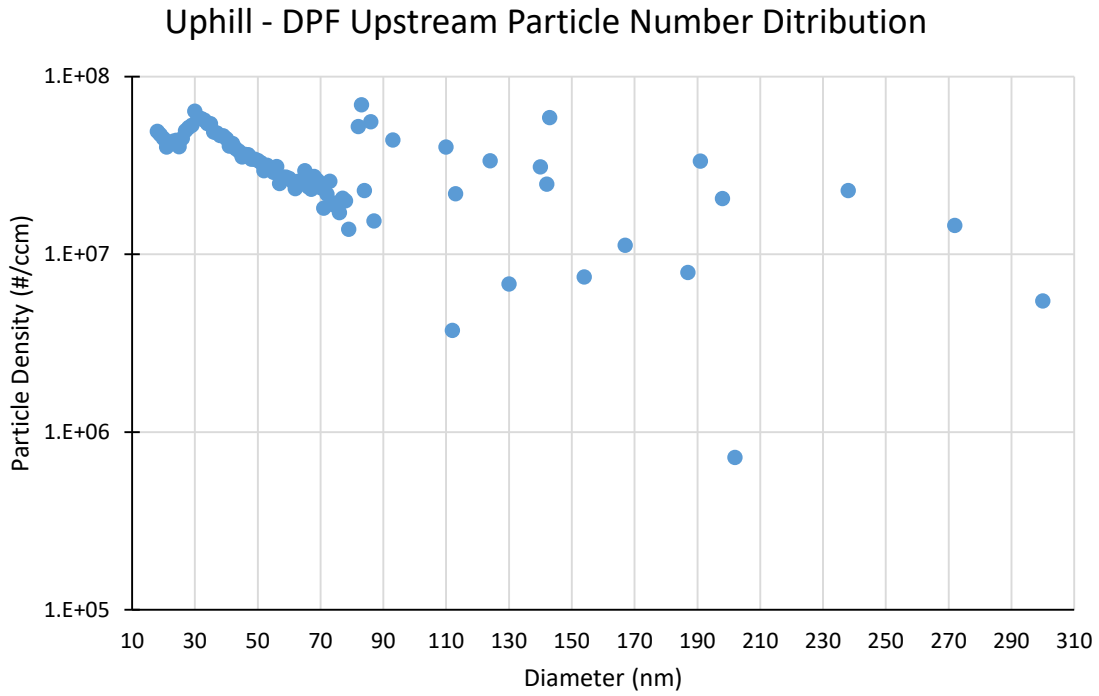


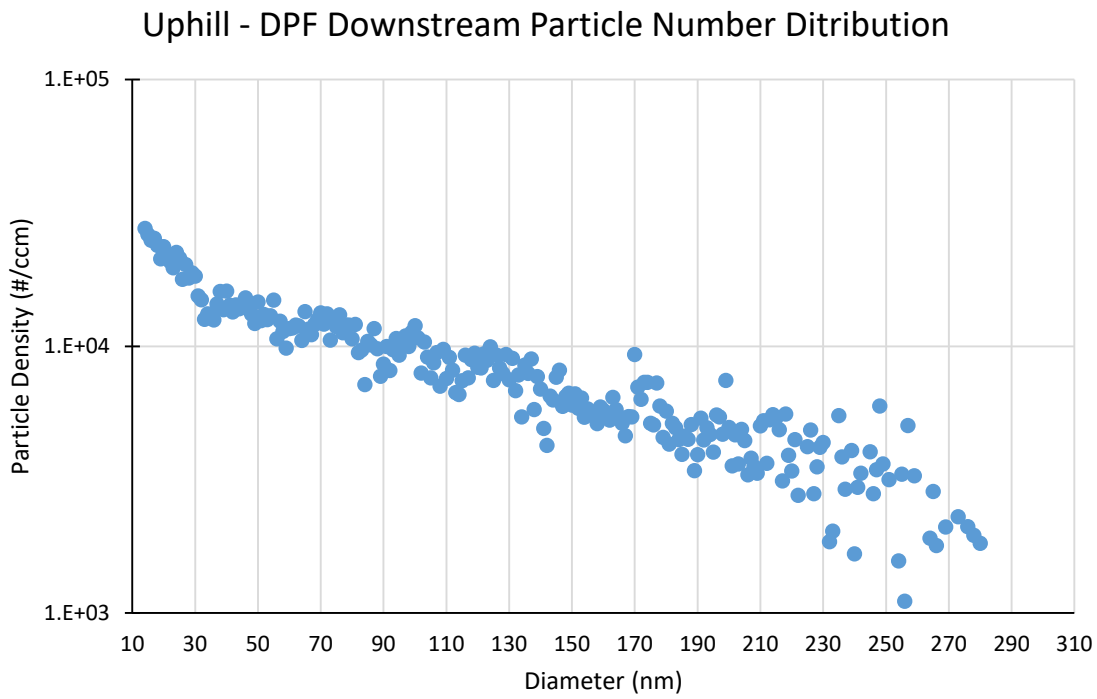


- Average particle before and after filter was 1.31×10^{15} [#/km] and 2.76×10^{11} [#/km] ;Respectively. The average filtration efficiency was 99.97% .

Route #2 – Particle Density Distribution

Route #2 : Urban Uphill

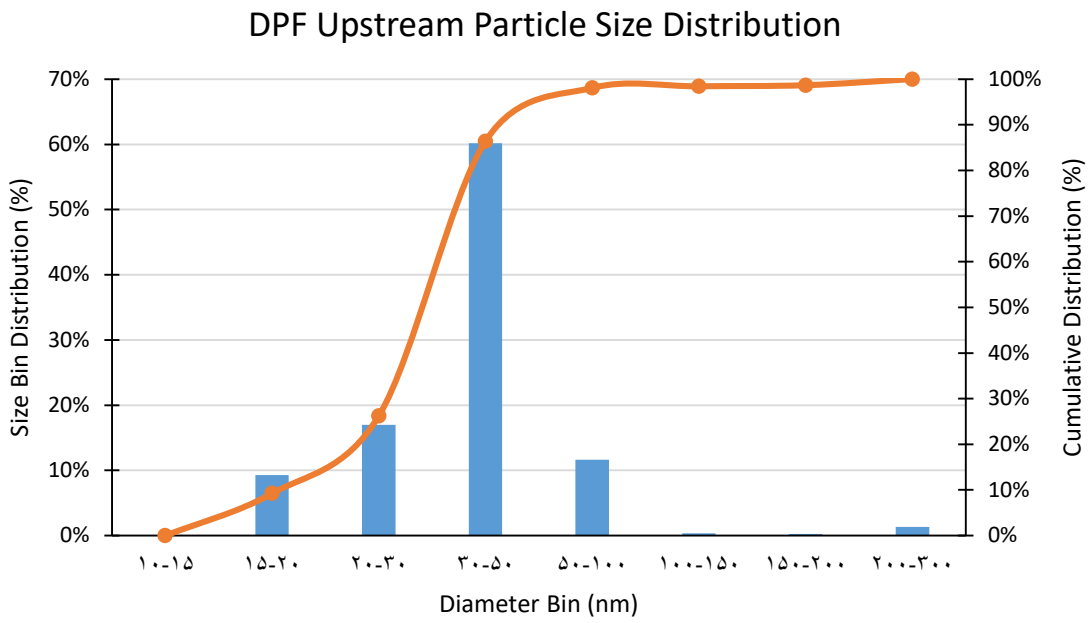


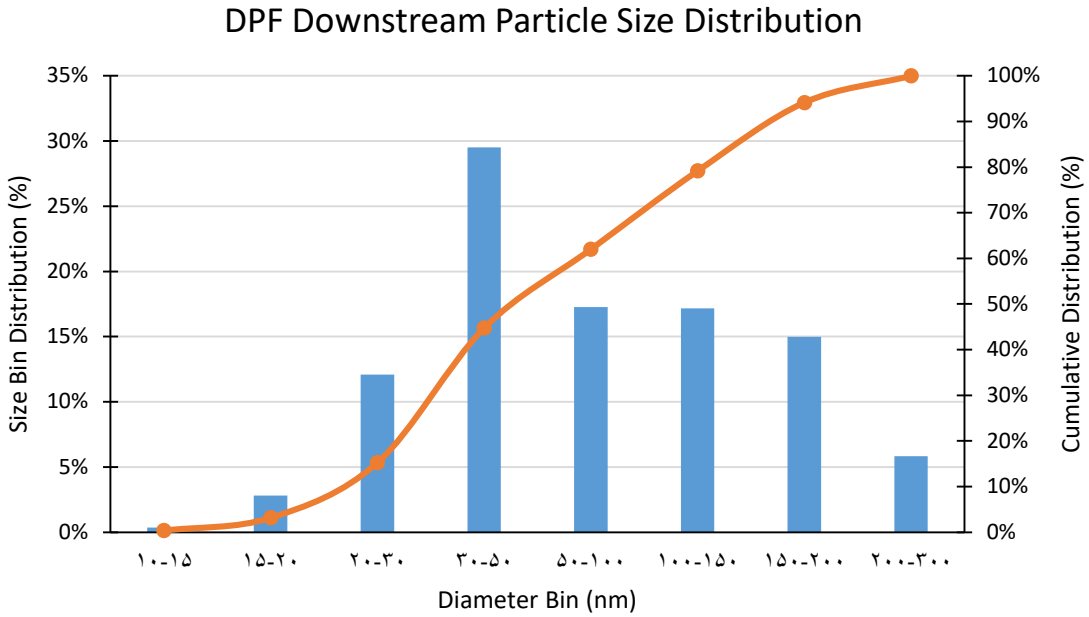


- Change of particle size distribution after filter

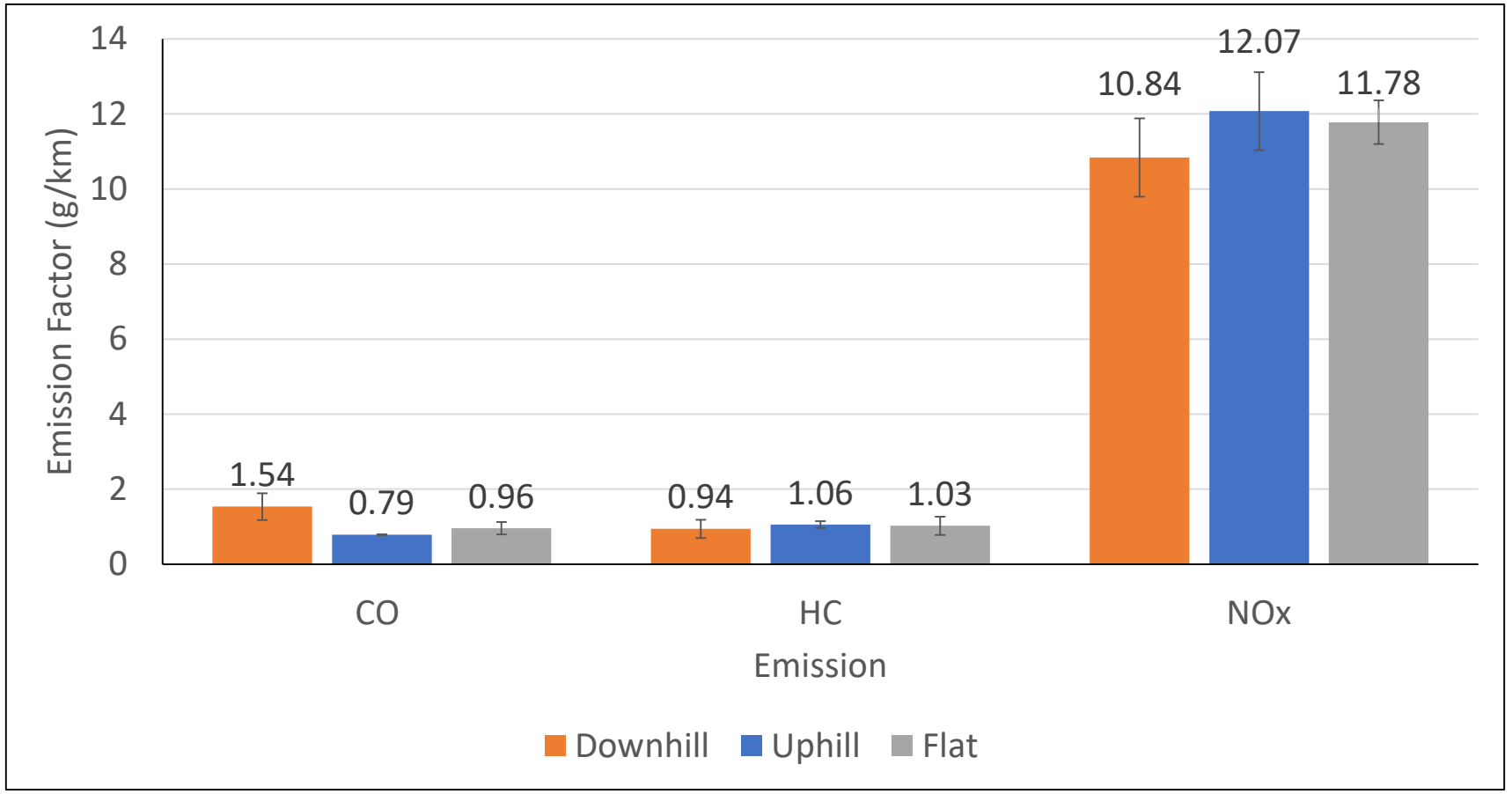
Route #2 – Particle Density Distribution

Route #2 : Urban Uphill





Average emission factors



Conclusion- part 1

- Despite of infrastructure challenges such as fuel sulfur content issues, high ash lubricating oil, and bad maintenance practices, filters remain reliable, robust, and functional, with efficiencies higher than expected under real-world driving conditions.

- NOx of current engines in operation is high and needs to be addressed.

- I/M program for retrofit and newfit vehicles needs to be stablished.

What would be the effect of Tehran elevation on diesel emission?

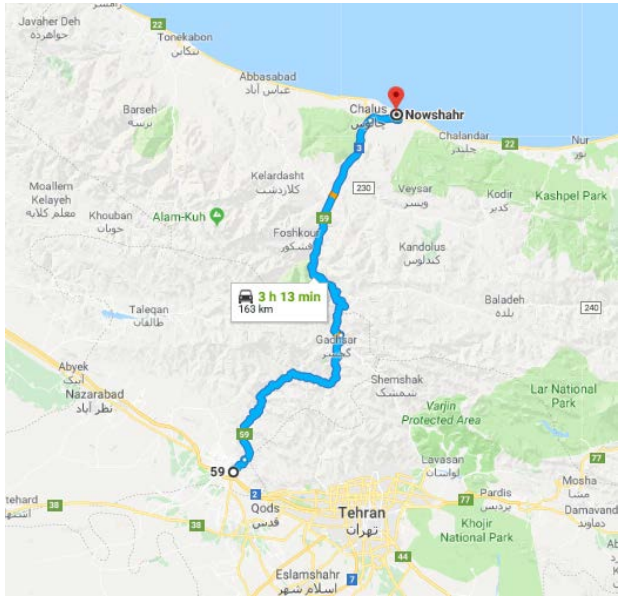
Research activity on effects of elevation started

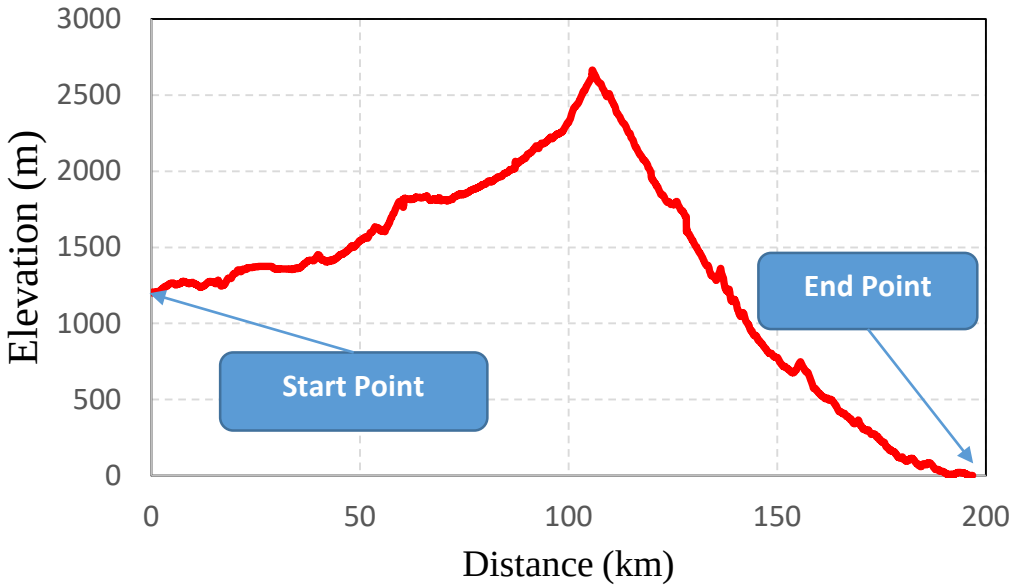
Engine Specification	
Manufacturer	Toyota
Engine Model	2KDFTV Turbocharged Diesel Engine
Emission Standard	EURO III
Emission Control	EGR + DOC
Configuration	Inline 4
Displacement	2494 cc
Cylinder Bore	92 mm
Piston Stroke	93 mm
Compression Ratio	18.5:1
Rated Power	75 kW @ 3600 RPM
Rated Torque	260 N.m @ 2000 RPM

Test Points

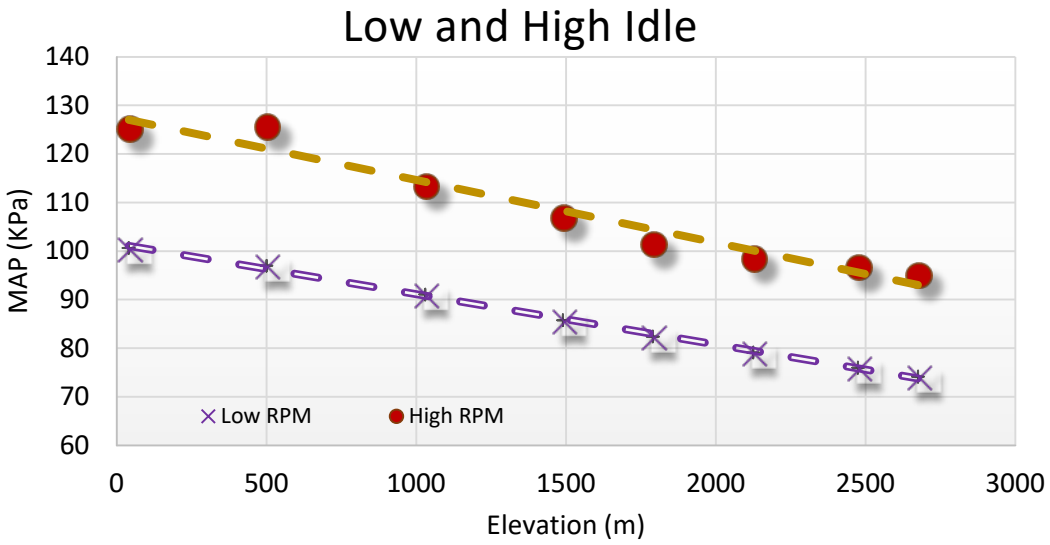
Elevation (m)	50	500	1000	1500	1800	2100	2400	2700
Low Speed Idle	✓	✓	✓	✓	✓	✓	✓	✓
High Speed Idle	✓	✓	✓	✓	✓	✓	✓	✓
Constant Speed 45 kph	✓	✓	✓	✓	✓	✓	✓	✓
Constant Speed 60 kph	✓	✓	✓	✓	✓	✓	×	✓

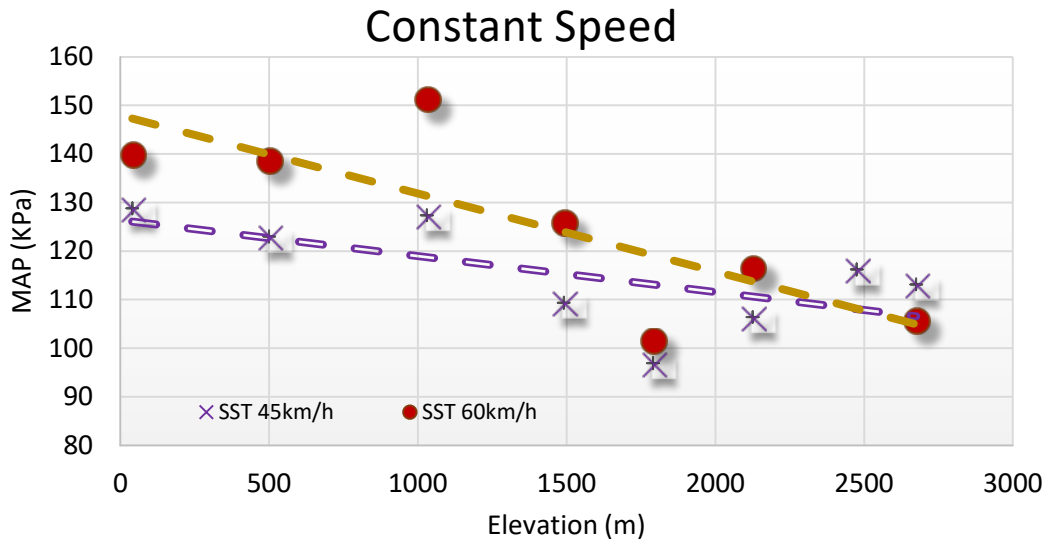
Test Route



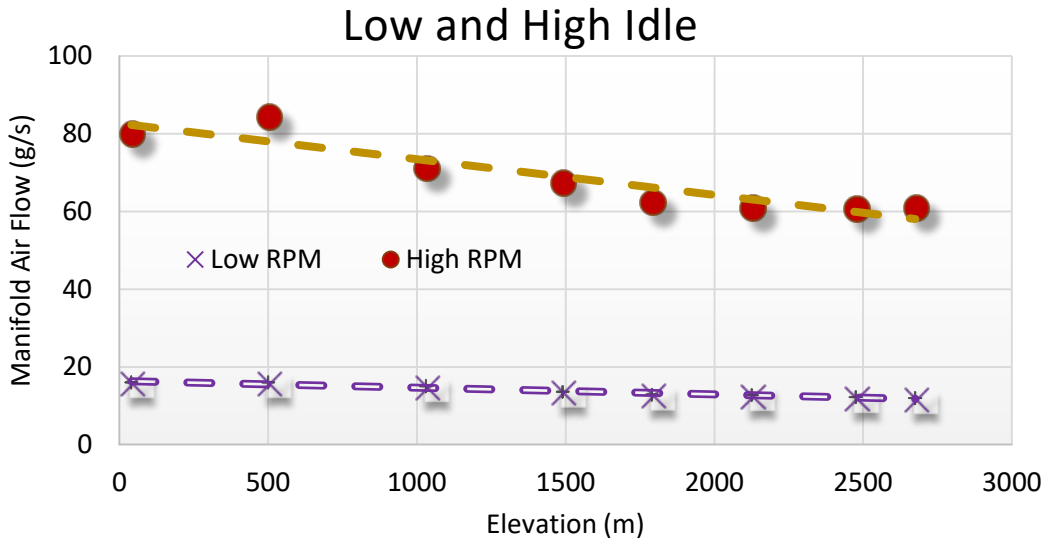


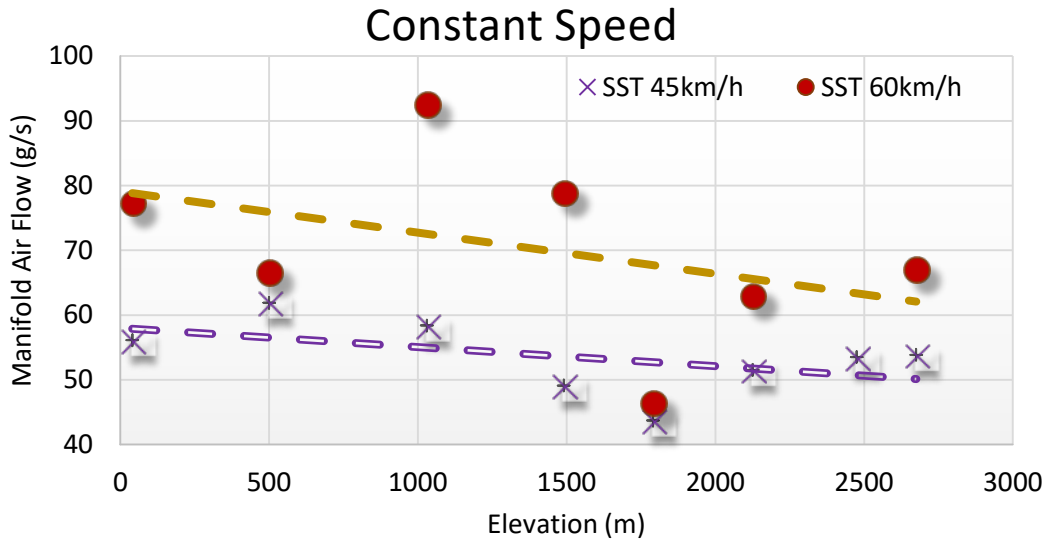
Manifold absolute pressure changes with elevation



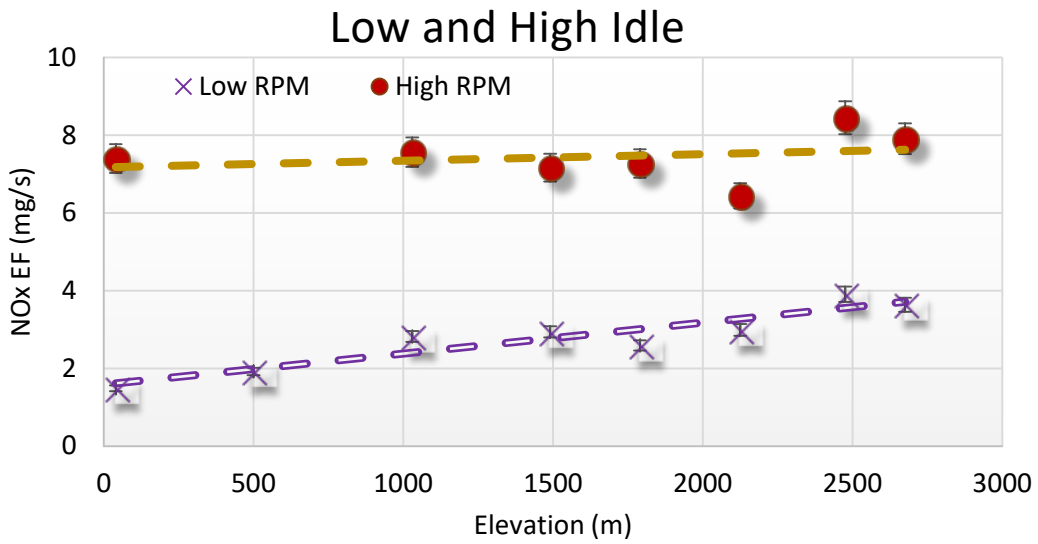


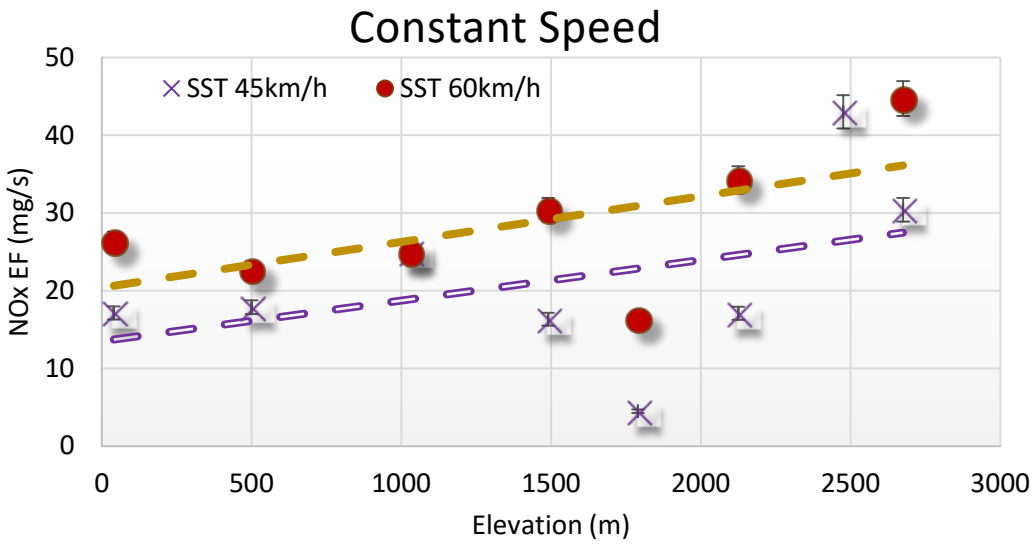
Mass air flow changes with elevation



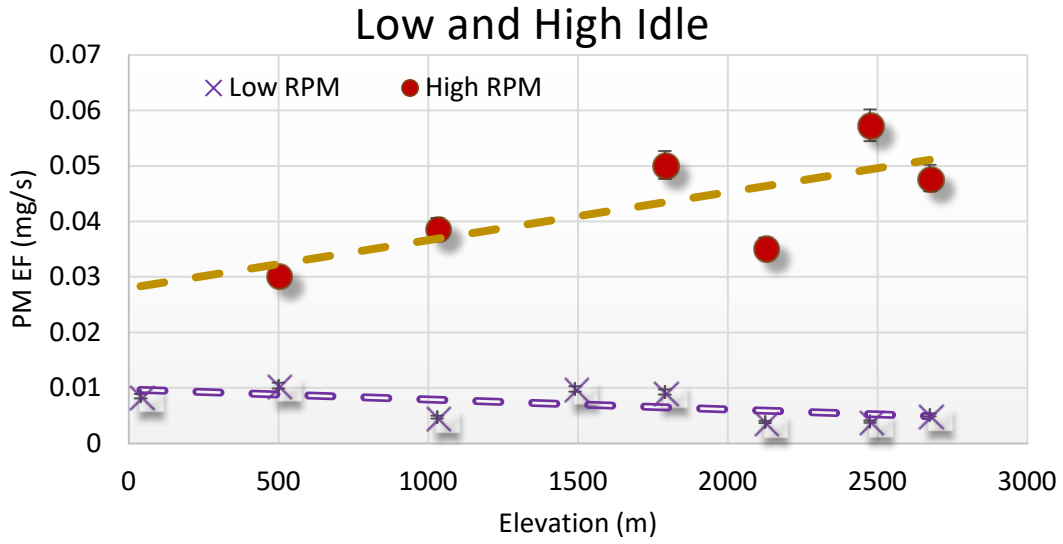


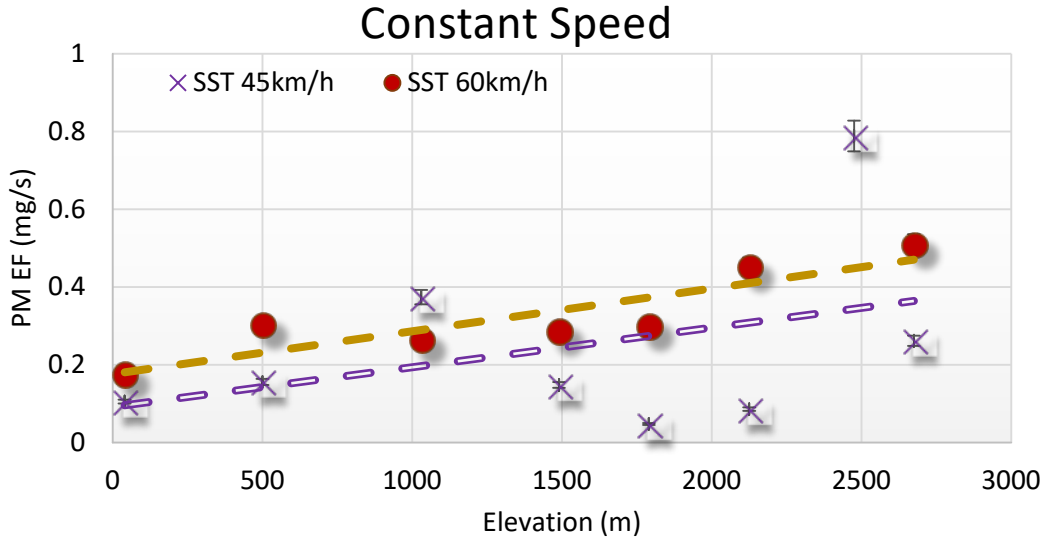
NOx Emission Factor As a Function of Elevation

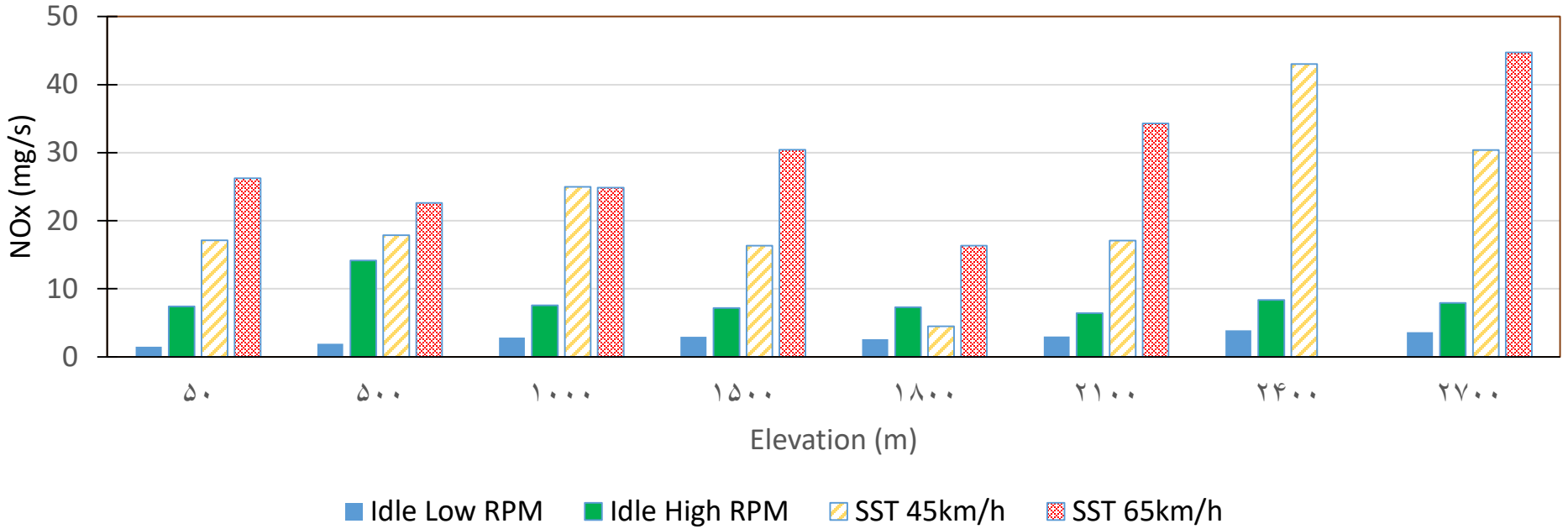


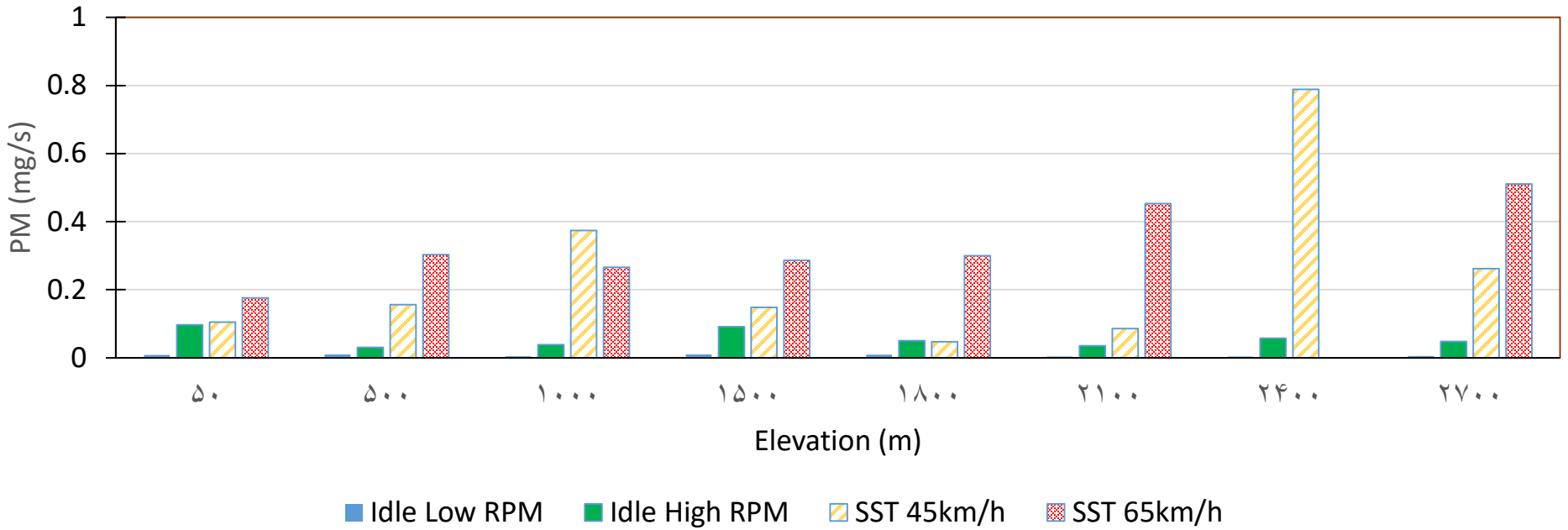


PM Emission Factor As a Function of Elevation






50
40
30
20
10
0
NOx (mg/s)
۵۰
۵۰۰
۱۰۰۰
۱۵۰۰
۱۸۰۰
۲۱۰۰
۲۴۰۰
۲۷۰۰
Elevation (m)
Idle Low RPM
Idle High RPM
SST 45km/h
SST 65km/h

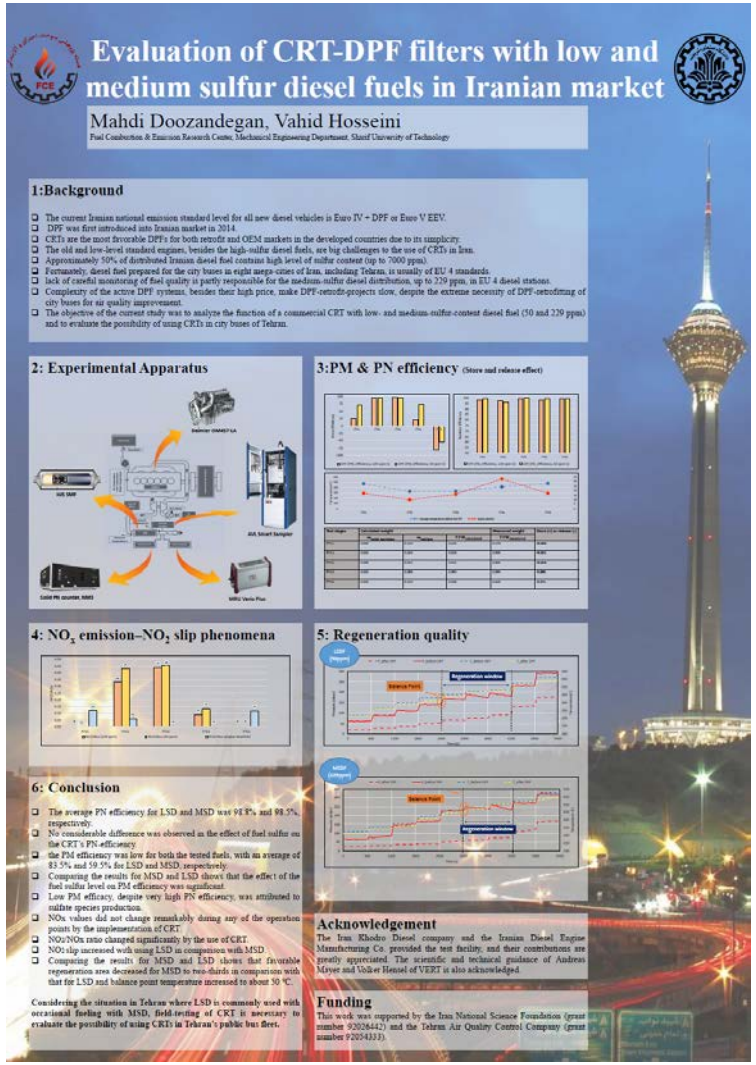

1
0.8
0.6
0.4
0.2
0
PM (mg/s)
۵۰
۵۰۰
۱۰۰۰
۱۵۰۰
۱۸۰۰
۲۱۰۰
۲۴۰۰
۲۷۰۰
Elevation (m)
Idle Low RPM
Idle High RPM
SST 45km/h
SST 65km/h

Conclusion- part 2

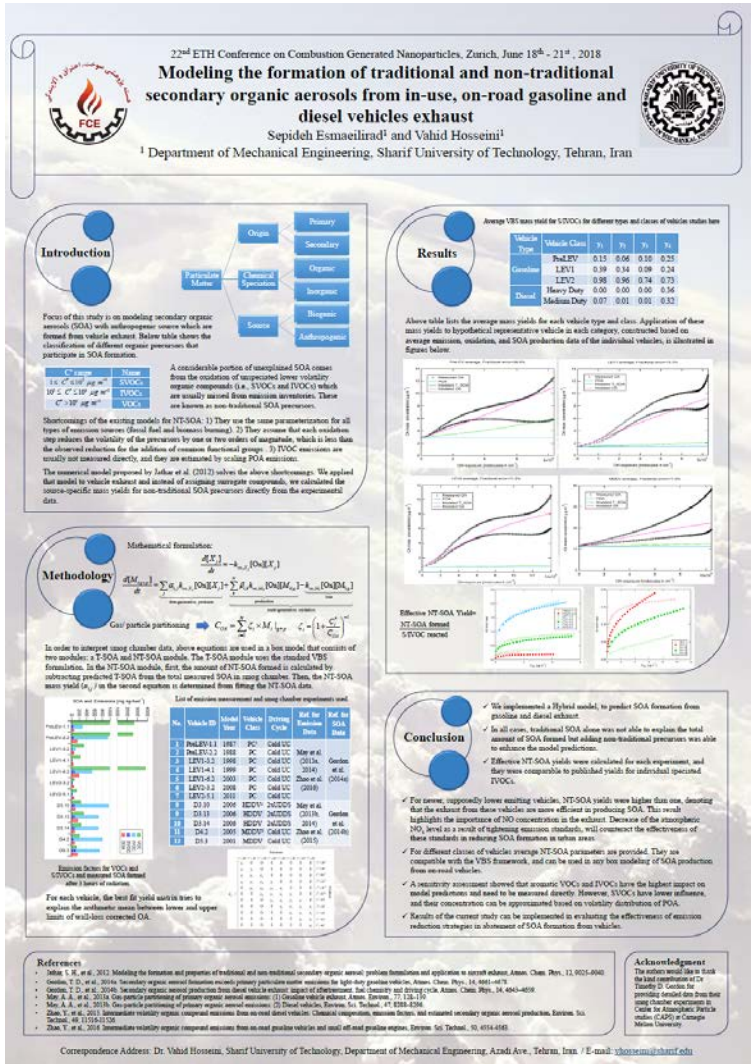
- It is quite obvious that elevation increases both NOx and PM emissions (close to two-folds).
- Engines are not tuned/calibrated at such high elevation.
- The role of ECU/OBD system is not known, needs to be investigated.
- Further studies are needed on the effect of elevation on filter efficiency and performances as millions of world population are living at high elevation.

Posters

#39


Evaluation of CRT-DPF filters with low and medium sulfur diesel fuels in Iranian market
Mahdi Doozandegan, Vahid Hosseini
Fuel Combustion & Emission Research Center, Mechanical Engineering Department, Sharif University of Technology
1:Background
The current Iranian national emission standard level for all new diesel vehicles is Euro IV + DPF or Euro V EEV.
DPF was first introduced into Iranian market in 2014
CRTs are the most favorable DPFs for both retrofit and OEM markets in the developed countries due to its simplicity.
The old and low-level standard engines, besides the high-sulfur diesel fuels, are big challenges to the use of CRTs in Iran.
Approximately 50% of distributed Iranian diesel fuel contains high level of sulfur content (up to 7000 ppm).
Fortunately, diesel fuel prepared for the city buses in eight mega-cities of Iran, including Tehran, is usually of EU 4 standards.
lack of careful monitoring of fuel quality is partly responsible for the medium-sulfur diesel distribution, up to 229 ppm, in EU 4 diesel stations.
Complexity of the active DPF systems, besides their high price, make DPF-retrofit-projects slow, despite the extreme necessity of DPF-retrofitting of city buses for air quality improvement.
The objective of the current study was to analyze the function of a commercial CRT with low- and medium-sulfur-content diesel fuel (50 and 229 ppm) and to evaluate the possibility of using CRTs in city buses of Tehran.
2: Experimental Apparatus
3:PM & PN efficiency (Store and release effect)
4: NO2 emission–NO2 slip phenomena
5: Regeneration quality
6: Conclusion
The average PN efficiency for LSD and MSD was 94.8% and 98.5%, respectively.
No considerable difference was observed in the effect of fuel sulfur on the CRT's PN efficiency
the PM efficiency was low for both the tested fuels, with an average of 83.5% and 59.5% for LSD and MSD, respectively.
Comparing the results for MSD and LSD shows that the effect of the fuel sulfur level on PM efficiency was significant.
Low PM efficacy, despite very high PN efficiency, was attributed to sulfate species production.
NOx values did not change remarkably during any of the operation points by the implementation of CRT.
NO2/NOx ratio changed significantly by the use of CRT.
NO2 slip increased with using LSD in comparison with MSD
Comparing the results for MSD and LSD shows that favorable regeneration area decreased for MSD to two-thirds in comparison with that for LSD and balance point temperature increased to about 50 °C.
Considering the situation in Tehran where LSD is commonly used with occasional fueling with MSD, field-testing of CRT is necessary to evaluate the possibility of using CRTs in Tehran's public bus fleet.
Acknowledgement
The Iran Khodro Diesel company and the Iranian Diesel Engine Manufacturing Co. provided the test facility, and their contributions are greatly appreciated. The scientific and technical guidance of Andreas Mayer and Volker Hensel of VERT is also acknowledged.
Funding
This work was supported by the Iran National Science Foundation (grant number 92026442) and the Tehran Air Quality Control Company (grant number 9209433).

#3


22nd ETH Conference on Combustion Generated Nanoparticles, Zurich, June 18th - 21st , 2018
Modeling the formation of traditional and non-traditional secondary organic aerosols from in-use, on-road gasoline and diesel vehicles exhaust
Sepideh Esmaeilirad[1] and Vahid Hosseini[1]
[1] Department of Mechanical Engineering, Sharif University of Technology, Tehran, Iran
Introduction
Methodology
Results
Conclusion
References
Acknowledgment
Correspondence Address: Dr. Vahid Hosseini, Sharif University of Technology, Department of Mechanical Engineering, Azadi Ave., Tehran, Iran / E-mail: vhosseini@sharif.edu

Thanks for your attention

Vahid Hosseini, Saeed Malekloo, Mahdi doozandegan, Behzad Ashjaiee
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- augrina consulting