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Risk characterization and Policy Recommendations Regarding the Diesel Exhaust and $PM_{2.5}$ in Beijing-Tianjin-Hebei Area

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Executive Summary

This report is motivated by the urgent desire of residents of Beijing and neighbor provinces, including Hebei and Tianjin, which is called Beijing-Tianjin-Hebei Region. This report aims to spur Beijing Environment Bureau into an action of updating policy to monitor and control the level of diesel exhaust in the densely-populated urban area.

Specifically, this report is going to:

1) Presents a brief overview of diesel fumes and its health effects;
2) Illustrate the relationship between fine particular matter and diesel exhaust;
3) Conduct a qualitative and quantitative review of available epidemiologic and experimental studies about diesel exhaust exposure;
4) Analyze the risk assessment of diesel exhaust;
5) Come up with recommendations to solve this air pollution problem.

Topic and Problem Statement

Vehicle emissions are the greatest source of Beijing's air pollution. According to Chai, an officer of Chinese Research Academy of Environmental Sciences, more than 5 million vehicles are registered in Beijing, and the number keeps increasing.

Diesel fumes, commonly known as diesel engine exhaust emissions, are a complex mixture of hundreds of constituents in forms of gas, vapor and fine particular matter. [1]The health effects could be acute and long-term. An acute exposure could lead to irritation of eyes, nose and lung. [2] Many health effects have association with diesel exhaust exposure, containing immunologic, respiratory, and cardiovascular effects. [3] Some studies show the correlation between inhalation of diesel fumes and lung cancer in long term.[4] Diesel play an important role in modern society and economy development. In transportation, trucks and lorries utilize diesel and majority of the rivers barges, freight trains and ocean-going ships are also powered by diesel. [5] Diesel-power machine is widely used in mining, farming and electronic industry.

Should the Environment Agency of Beijing introduce a regulation to monitor and control diesel fumes in air?

Background

For several decades, Beijing has suffered from heavy air pollution. In December 2o16, a thick layer of gray smoke covered the capital for five days. Most schools were closed after the red alert of air pollution was issued. [1] Some citizens wore protective masks to work or shop, which was a common scene in winter. This serious air pollution not only existed in Beijing, but all neighboring provinces experienced this. Beijing has 21.70 million residents and the neighboring provinces including Tianjin, Hebei, Shanxi, Henan, etc. are densely populated. The health effect is bigger in this densely populated area than air pollution in other area.

Diesel exhaust is the main factor to the air pollution in Beijing. Diesel is widely used in construction, public transportation, mining and agriculture. Miners, railroad workers, equipment operators, and truck drivers have high exposure to diesel exhaust (DE). With the process of industrialization and urbanization, DE is more common in many areas. According to list of the U.S. Environmental Protection Agency (U.S. EPA), diesel exhaust contains 40 hazardous air pollutants. World Health Organization(WHO) claims diesel exhaust is carcinogenic to humans as Group 1, which means there is sufficient evidence to support this claim.

Diesel exhaust is a major contributor to fine particulate matter pollution. As the most common air pollutants, particulate matter(PM) is mix of solid particles and liquid particles found in the air. [6] Long term exposure to fine particles can aggravate asthma and affect lung function. [5] PM_{10} refers to inhalable particles which are smaller than 10 micrometers. $PM_{2.5}$ are particles with diameter smaller than 2.5 micrometers. [7] PM2.5 are known to trigger or worsen chronic disease such as asthma, heart attack, bronchitis and other respiratory problems. [10] According to EPA air quality standards for particle pollution, 35.5 to 55.4 ug/m^3 of $PM_{2.5}$ is considered unhealthy for sensitive groups including people with respiratory or heart disease, the elderly and children. [12] The National Ambient Air Quality Standards set a limit of annual $PM_{2.5}$ below 12.0 μg/m^3. [13]

In Beijing, the PM 2.5 has been an average of 100 micrograms per cubic meter from 2008 to 2014, which is about six times what the US EPA defined as safe. Beijing has a series of regulations to control emission and also limit truck hours of operation. However, air quality is a regional issue. There is inconsistency in the degree and speed of implementation between Beijing and the surrounding cities and counties, which makes this condition hard to control. [21]Residents in Beijing and neighboring provinces are concerned about this serious air pollution condition but they can only take the individual approach of wearing anti-pollutant masks.

Study(Year)	Study design	Study size	Finding	Limitation
Salvi(1997)	Clinical trial	15 healthy nonsmoking volunteer (11 males, 4 females)	At high ambient concentrations, acute short-term DE exposure produces a well-defined and marked systemic and pulmonary inflammatory response in healthy human volunteers, which is underestimated by standard lung function measurements.	It concluded particulate component of DE is mainly responsible for the inflammatory response while it doesn't effectively exclude the influence of other components in DE. It mentions about informed consent but may have ethical issue.
Nemmar(2003)	experimental	Hamsters	The intratracheal instillation of DEPs induces lung inflammation as well as a rapid activation of circulating blood platelets, which was considered be consistent with the reported clinical occurrence of thrombotic complications after exposure to pollutants.	It provides plausible biological basis for association between DEPs and cardiovascular disease increasing. The biggest issue is whether hamsters can be used to predict human response to DEPs.
Peresen(2010)	Historical cohort study	2,037 bus drivers	In this long-term follow-up study we found little evidence of a causal association	

			between employment as an urban bus driver in Denmark and subsequent cancer .	
Attfield(2012)	Cohort study	12,315 non-metal miners	Exposure to diesel exhaust increases risk of mortality from lung cancer	It does not adjust the possible confounding effect of smoking in this study.
Latifovic(2015)	population-based case–control study	658 bladder cancer cases and 1,360 controls	Exposure to high concentrations of diesel engine emissions may increase the risk of bladder cancer	It utilized self-reported data for lifetime occupational histories, which might have recall bias.
Silverman(2012)	nested case–control study	12,315 workers	Diesel exhaust exposure may cause lung cancer in humans and may represent a potential public health burden	The quantification of exposure doses is not available. Silverman mentioned two limitations for his study. One is the source of potential confounders might be vague. Another is the estimates of diesel exposure might be imprecise.
Schisler(2016)	experimental	6 healthy human	Substantial pro-inflammatory changes that could participate	

			in the promotion of both acute events or progression of chronic inflammatory vascular disease.	
Hosseini(2015)	blinded crossover human study	12	In vivo allergen and DE co-exposure results in elevated CD4, IL-4, CD138 and NE in the respiratory submucosa of atopic subjects, while eosinophils and mast cells are not changed.	
Carlsten(2016)	Case-control	18 (11 women and 7 men)	Inhalation of diesel exhaust at environmentally relevant concentrations augments allergen-induced allergic inflammation in the lower airways of atopic individuals and the GSTT1 genotype enhances this response. Allergic individuals are a susceptible population to the deleterious airway effects of diesel exhaust.	Between exposure and lung sampling, there is 48 h delay may loss some immediate effects.
Si(2016)	cross-sectional survey	162 Road transport workers	96.7% RTWs in Australia were probably exposed	Si et al does not consider age or smoking

			to diesel exhaust. Driving and vehicle maintenance-related tasks were the major source of carcinogen exposures among Road transport Workers.	condition as potential confounders.

The strengths among two cohort studies include large sample size and quantitative assessment and analysis process. Every included studies mention about ethical review and informed concern. Most studies in 2016 have an appropriate quantitative estimates of exposure.

The major limitation is some included studies do not have propitiate adjustment of the potential confounders such as smoking and age. Possible limitation may include exposure misclassification.

Characterization of the Risk

Hazard identification

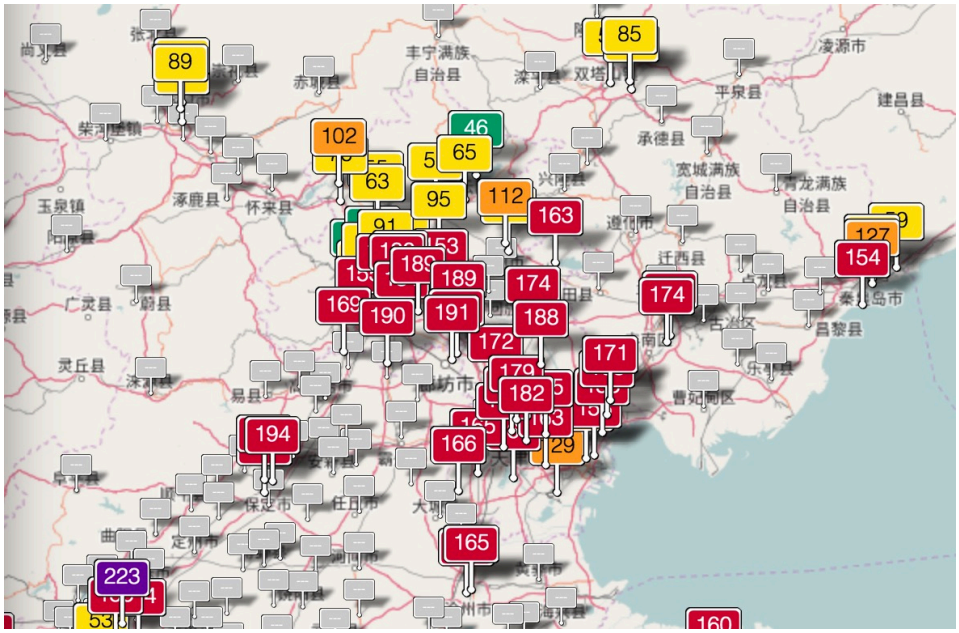
Diesel exhaust is the major resource of particulate matter. Particulate matter (PM) air pollution contributes to cardiovascular morbidity and mortality. [8] Many studies have found that exposure to PM increase premature death from lung disease. [9] PM2.5 is also known to trigger or worsen chronic disease such as asthma, heart attack, bronchitis and other respiratory problems. [10] Jiřík et al found the incidence of pulmonary disease and bronchial asthma in PM2.5 highly-density area is higher than general population. Cox et al confirmed the positive association between stroke and heart attack risk with PM2.5 by investigating self-reported risk in a large data set.

Exposure assessment

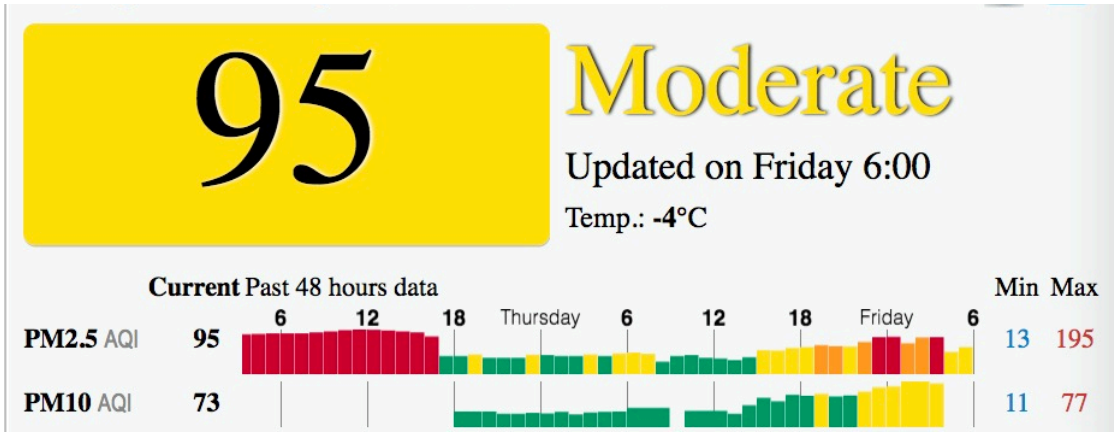
The major route of exposure is inhalation of DE. A male who exposure to 5 μg/m3 of elemental carbon for 45 years, beginning at age 20 and ending at age 65, would has a lifetime excess risk of lung cancer of 1.6%. [11]

As diesel exhaust is "highly complex mixture", scientist always use surrogate to measure the level of exposure. Carbon could be selected as an exposure surrogate, since more than 80% diesel particle matter are carbon. [14] However, carbon in the organic fraction(OC)also exist in other source of pollution such as smoking. So OC is not an ideal selection for surrogate. [15] In contrast, elemental carbon(EC), which refers to carbon in the soot particle core, exist little in cigarette and wood smokes. What's more, gasoline emission contains far more less EC than diesel. [16] So elemental carbon is an ideal surrogate to measure particulate fraction in diesel exhaust.

Generally, there is a remarkable seasonal variability in PM2.5 concentrations. The highest level of PM2.5 is during the winter and the lowest is in summer. [28]



This picture shows the Real-time Air Quality Index of Beijing-Tianjin-Hebei Region at 18:00 February 23rd 2017. (Source: http://aqicn.org/city/beijing/us-embassy/)



This graphic shows the 48 hours PM2.5 and PM10 index on February 23rd 2017. Location is US Embassy in Beijing. (Source: http://aqicn.org/city/beijing/us-embassy/)

Dose response

A plethora of studies suggest the dose relationship between DE exposure and lung diseases. Ishihara et al suggest a dose response relationship in regard to duration and concentration of exposure. [14] Larcombe et al argue that the route of exposure affects the

dose-relationship, inhalation generally displaying more realistic dose-response relationships than intranasal instillation, which shows little influence of dose. [15] However these are animal experimental studies. The quantitative dose-response estimates could not be developed due to lack to information. [16]

Risk characterization

In order to protect public population against adverse health effects, EPA has established an annual NAAQS for PM2.5 at a level of 15 ug/m^3. DE is a complicated mixture to measure, protective levels for PM2.5 may use as a measure of protection from effects associated with diesel exhaust. [16]

The Landscape

Key stakeholders

- Citizens in Beijing-Tianjin-Hebei region
  - Residents live or work in Beijing-Tianjin-Hebei region
  - Sensitive group who is more vulnerable to this diesel exhaust or PM2.5, including children and infants, senior citizens and allergic population.
- Motor vehicle manufacturers
- Freight transportation sector
  - Logistic companies
  - Carries
- Natural Gas Fueling Station
- Construction sector
- Workers with occupational exposures to diesel exhaust
  - Rail workers
  - Trucks drivers
  - Professional drivers
  - Mechanics
  - Construction workers
- University and Environmental Research Center
- Healthcare professional organizations, and other health-related agencies
- Ministry of Environmental Protection's Vehicle Emissions Control Centre
  - MEP is in charge of developing, drafting, and approving the vehicle and engine emission standards. In addition to National Standards, which are mandatory nationwide, Environmental Standards may apply to industries that have an impact on the quality of the environment, and Local Standards may be issued by local governments.
- Provincial Environmental Protection Bureau
  - Beijing Environmental Protection Bureau
  - Tianjin Environmental Protection Bureau
  - Hebei Province Environmental Protection Bureau
- Media
- Social media
  - WeChat

  - Sina Weibo
- Environmental organization
- Vehicle and engine manufacturers

Applicable regulatory agencies and environmental acts

1) The International Council on Clean Transportation
2) Low Emission Zone(LEZ) in Germany

   A low emission zone is defined area where only allowed vehicle meet low-emission standard to access. Vehicles receive a colorful sticker to show whether they are low-emission. The introduction of low emission zone is effectively speed up the replacement of old high-pollution vehicles. This process of replacement is from 2008 and divided into two phase, so residents could have enough time to retrofit their vehicles or purchase new ones. Qadir et al found the average concentration of EC from traffic factor decreased from 1.1 to 0.5 mg/m3 after the implementation of the LEZ.[22]
3) Unite States EPA New England control diesel exhaust

   EPA in Unite States set up stringent emission standards for new diesel engines and fuel. [23] EPA also encourages schools, communities to develop anti-idling policy. EPA start a collaboration with the freight industry to reduce emissions, called SmartWay Transport Partnership. [23]
4) Unite State EPA collaborates with China

   EPA has collaborated with China's Ministry of Environmental Protection, city-level Environmental Protection Bureau to share experience and strategy in reduction air pollutants. [24] For example, EPA collaborate with Shanghai Environmental Monitoring Center to establish the AirNOW international monitoring system, which is also applicable to Beijing. [25]

Social and behavioral factors

The reasons behind a company or operator of diesel vehicles and equipment willing to reduce emission could fit into three categories [29]:

- Because they have to (high emitting vehicles are banned to use in some region);
- Because it is financial beneficial to do so;
- For environmental reason;

Economic Consideration

The benefit of reducing diesel emission is mainly health benefits. Less particular matter pollution may reduce hospital visiting. This benefit can be measure by monetary value of lessening the health burdens created. For example, cost of illness(COI) could be used to estimate total costs incur due to a disease, including the total cost of medical treatment and loss in productivity. [30]

Options and Recommendation Section

- **Diesel standard**
  The Beijing-Tianjin-Hebei region should adopt more stringent fuel standard to reduce amount of sulfur in diesel fuel, especially for on-road truck or bus.
- **Emission standard**
  Beijing-Tianjin-Hebei region should expedite implementation of new emission standards for heavy-duty vehicles. Some diesel vehicles currently in use do not have diesel particulate filter(DPF). These old vehicles could retrofit to get a DPF.
- **Idling limit**
  Bus companies should implement a series of idling reduction measures including training drivers, posting anti-idling signs, performing periodic "walk-throughs" of bus lots to ensure that no excessive idling occurs.
- **Low Emission Zone**
- **Drivers training program**
  Regular maintenance to keep trucks in good working condition should be performed.

Some experts have suggested skipping China V and moving directly to the China VI. However, China V has already been announced and manufacturers have already started to bring production into line with national criteria. Moving to the more stringent standard-China VI now could be not cost effective.

Table 1. Heavy-duty vehicles' contribution to particulate emission

	Percent of vehicles that are heavy-duty vehicles	Percent of vehicle particulate emission that are from heavy-duty vehicles
China	**10%**	**83%**
United States	5%	36%
EU	11%	47%
Global	11%	71%

*data from 2015 International Council on Clean Transportation

The best solution is implement diesel particle filter (DPF) retrofit of heavy-duty vehicles. It is obvious to tell from **Table1** that percent of heavy-duty vehicles is below the global average, while this 10% heavy-duty vehicles contribute to 83% particulate emission.

Implement retrofit of heavy-duty vehicles should started with evaluating and determining of what type of vehicles are suitable. Space is not a problem for heavy-duty vehicles. Whether it cost-effective to retrofit a vehicle should be taken into consideration.

The second step is to decide which technologies to use. The performance of retrofit technology and the budget available is the main consideration. Due to budget consideration, Beijing and Tianjin, these two metropolitan cities, might take more advanced technology than Hebei province.

The third step is testing and certification after retrofit. One third-party agency should take

responsibility of testing and certifying the vehicles if they meet the emission standard.

Reference:

1. https://www.nytimes.com/2016/12/16/world/asia/beijing-air-pollution.html?_r=0
2. Beijing population 2016. http://countrydigest.org/beijing-population/
3. https://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf
4. Volodzko, et al. Is Living in Beijing Really Like Smoking 40 Cigarettes a Day? http://thediplomat.com/2015/09/is-living-in-beijing-really-like-smoking-40-cigarettes-a-day/
5. Health and Environmental Effects of Particulate Matter (PM) https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm
6. Seinfeld, John; Spyros Pandis (1998). *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change* (2nd ed.). Hoboken, New Jersey: John Wiley & Sons, Inc. p. 97.
7. Particulate Matter (PM) Basics. United States Environmental Protection Agency. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#effects
8. Brook, Robert D., et al. "Particulate matter air pollution and cardiovascular disease." Circulation 121.21 (2010): 2331-2378.
9. Paulin, Laura, and Nadia Hansel. "Particulate air pollution and impaired lung function." F1000Research 5 (2016).
10. What is PM2.5 and Why You Should Care. Bliss Air Website. https://blissair.com/what-is-pm-2-5.htm
11. Steenland, Kyle, James Deddens, and Leslie Stayner. "Diesel exhaust and lung cancer in the trucking industry: exposure–response analyses and risk assessment." *American Journal of Industrial Medicine* 34.3 (1998): 220-228.
12. Air Quality Index - A Guide to Air Quality and Your Health. https://www.airnow.gov/index.cfm?action=aqi_brochure.index
13. NAAQS Table. https://www.epa.gov/criteria-air-pollutants/naaqs-table

14. Noll, J. D., et al. "Relationship between elemental carbon, total carbon, and diesel particulate matter in several underground metal/non-metal mines." *Environmental science & technology* 41.3 (2007): 710-716.
15. Birch, M. E., and R. A. Cary. "Elemental carbon-based method for monitoring occupational exposures to particulate diesel exhaust." *Aerosol Science and Technology* 25.3 (1996): 221-241.
16. Birch, M. Eileen. "Monitoring of diesel particulate exhaust in the workplace." *NIOSH Manual of Analytical Methods (NMAM)* 2154 (2003).
17. Ishihara, Yoko, and Jun Kagawa. "Dose-response assessment and effect of particles in guinea pigs exposed chronically to diesel exhaust: analysis of various biological markers in pulmonary alveolar lavage fluid and circulating blood." *Inhalation toxicology* 14.10 (2002): 1049-1067.
18. Larcombe, Alexander N., et al. "Route of exposure alters inflammation and lung function responses to diesel exhaust." *Inhalation toxicology* 26.7 (2014): 409-418.
19. United States. Environmental Protection Agency. *Health assessment document for diesel engine exhaust*. National Center for Environmental Assessment, 2002.
20. Health Effects Institute. Diesel Working Group. *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects: a Special Report of the Institute's Diesel Working Group*. Health Effects Institute, 1995.
21. Yang, Zifei, et al. "Review of Beijing's CompRehensive motoR vehiCle emission ContRol pRogRams." *communications* 49.30 (2015): 847129-102.
22. Qadir, R. M., et al. "Concentrations and source contributions of particulate organic matter before and after implementation of a low emission zone in Munich, Germany." *Environmental pollution* 175 (2013): 158-167.
23. Gaines, Linda, and Terry Levinson. "Idling: Cruising the Fuel Inefficiency Expressway." (2009).
24. EPA Collaboration with China. EPA website.https://www.epa.gov/international-cooperation/epa-collaboration-china
25. Dawes, S., B. Burke, and Lei Zheng. "AIRNow-I Shanghai: Crossing cultures, sharing knowledge." *Center for Technology in government, Albany, New York* (2011).

26. Jiřík, Vítězslav, et al. "How serious are health impacts in one of the most polluted regions of Central Europe?." *Reviews on Environmental Health* (2016).
27. Cox, Louis Anthony Tony. "Socioeconomic and air pollution correlates of adult asthma, heart attack, and stroke risks in the United States, 2010–2013." *Environmental Research* 155 (2017): 92-107.
28. Kodjak, Drew. "Policies to reduce fuel consumption, air pollution, and carbon emissions from vehicles in G20 nations." *The International Council on Clean Transportation* (2015).
29. Zhang, Yan-Lin, and Fang Cao. "Fine particulate matter (PM2. 5) in China at a city level." *Scientific reports* 5 (2015): 14884.
30. Reducing Particulate Matter Emissions from Diesel Vehicles and Equipment. http://www.healthyair.org.uk/documents/2013/10/black-carbon-retrofit-guidance.pdf
31. Jo, Changik. "Cost-of-illness studies: concepts, scopes, and methods." *Clinical and molecular hepatology* 20.4 (2014): 327-337.