

Policy Options to Manage High-pollution On-road Diesel Vehicles Based on Excessive Emission Grades in Seoul

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Summary

The degree of gas emission from diesel cars is proportional to its age. The Seoul Metropolitan Government(SMG) needs customized approach for worn-out diesel cars which emit an excessive amount of greenhouse gas.

1. Introduction

The recent Volkswagen's emissions scandal, in which the German automaker was excoriated for falsely selling cars fitted so-called "defeat devices." This offense has heaped attentions on the emission performance of diesel-fuelled cars. According to a recent study, diesels perform poorly in reducing auto emissions, failing to meet the emission regulation standards. Meanwhile, decrepit diesel cars, whose number is on the rise in Seoul, emit an excess of pollutants. Such issues pose a challenge to the management of Particulate Matter (PM) and Nitrogen Oxides (NOx), the harmful substances discharged by diesel cars. Under these circumstances, the Seoul Metropolitan Government (SMG) ought to introduce a diesel car emission control system. It would help eliminate threats to the public health, thus achieving an environmentally healthy city.

Decrepit diesel cars, whose number is on the increase, are the main source of excessive auto emissions

In Seoul, the share of diesel cars in Seoul is rising every year. Along with this trend, the share of battered diesel-fueled cars is increasing. It has been confirmed that the average emission density of vehicles increases as they age. Yet the owners

tend to be reluctant to fix their old cars to meet the expected standards for emission control. It is because of higher maintenance costs arisen from, for instance, the increased cost of replacing worn-out components. Concern grows over that it may trigger a vicious cycle of aggravating pollution. Meanwhile, the number of dilapidated diesels is growing. They release an excess of auto emissions, which are the primary air pollutants.

SMG does not adequately utilize information to diagnose the emission level of vehicles in Seoul and set the priorities for emission control

Every year, over one million vehicles registered in Seoul, including gasoline-fuelled and diesel-powered, are tested for exhaust gas emission. At present, the test result is only used to decide whether the emission level of a car is acceptable under the emission regulation standards. Meanwhile, the diagnosis of excessive exhaust gas emission only identifies vehicles that release auto emissions more than 150 percent of the permitted amount. These vehicles are called “high-density exhaust gas emitting vehicle.” The amount of pollutants discharged by diesel-powered cars reportedly accounts for 42.4 percent of total PM-10 in Seoul. Yet, SMG does not adequately use available information that can help assess the excess pollutant emission of diesels in Seoul.

This research develops methods for evaluating and managing emission from diesel vehicles.

2. Main Findings

The primary culprit of air pollution in Seoul is motor vehicle emissions

Motor vehicle emissions are the largest source of Particulate Matter (PM) and Nitrogen Oxides (NOx) in Seoul. In detail, out of 1,858 ton of PM-10 (excluding fugitive dust²¹), 793 ton (about 42.7 percent) comprises auto emissions. Cars

release 730 ton of PM-2.5, which represent approximately 44.1 percent of total PM-2.5 (1,657 ton). The amount of NOx emitted by vehicles stands at 27,652 ton, accounting for about 44.3 percent of total NOx (62,363 ton).

[Table 1] The Volume of Air Pollutants Emitted by Each Emission Source (As of 2012)
(Unit: ton)

Emission Source	PM-10		PM-2.5		NOx	
Non-Industry	234	12.6%	167	10.1%	19,693	31.6%
Energy Industry	13	0.7%	13	0.8%	599	1.0%
Manufacturing Industry	1	0.1%	1	0.0%	296	0.5%
Motor Vehicles on the road	793	42.7%	730	44.1%	27,652	44.3%
Non-Vehicles on the road	634	34.1%	583	35.2%	12,769	20.5%
Area Sources*	35	1.9%	32	1.9%	599	1.0%
Waste Disposal	17	0.9%	14	0.8%	743	1.2%
Natural Sources**	131	7.0%	117	7.1%	13	0.0%
Total	1,858	100.0%	1,657	100.0%	62,363	100.0%

*Area sources refer to pollution sources consisted of multiple, small-scale pollution sources that discharge hazardous air pollutants in a specified area, such as a residence

**Natural sources are ones emitting air pollutants without human involvement

Source : 2012 Report on the Volume of Air Pollutant Emissions, National Institute of Environmental Research, 2014

The larger and older the diesel cars are, the more the air pollutants

In particular, trucks and recreational vehicles (RVs) release a large volume of auto emissions: The amount of PM-10 and NOx discharged by trucks for 44.9 percent and 39.8 percent, respectively. RVs, on the other hand, is responsible for 44.6 percent of total PM-10 and 13.8 percent of the total NOx.

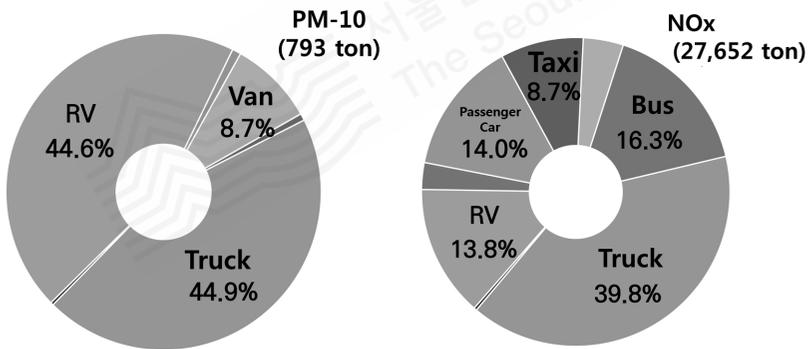
²¹ Fugitive dust refers to the sum of small airborne particles that directly spread to air without going through a certain vent. It is mostly hazardous and produced at construction sites.

[Table 2] Auto Emissions from Each Vehicle Type (As of 2012)

(Unit: ton)

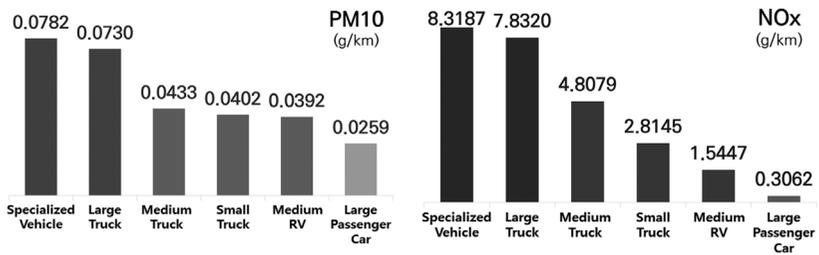
Vehicle Type	PM10		PM2.5		NOx	
Passenger Car	7	0.9%	6	0.9%	3,868	14.0%
Taxi	0	0.0%	0	0.0%	2,414	8.7%
Van	69	8.7%	63	8.7%	1,160	4.2%
Bus	5	0.7%	5	0.7%	4,514	16.3%
Truck	356	44.9%	328	44.9%	11,019	39.8%
Specialized Vehicle	2	0.3%	2	0.3%	92	0.3%
Recreational Vehicle (RV)	354	44.6%	325	44.6%	3,817	13.8%
Motorcycle	0	0.0%	0	0.0%	767	2.8%
Total	793	100.0%	730	100.0%	27,652	100.0%

Source : 2012 Report on the Volume of Air Pollutant Emissions, National Institute of Environmental Research, 2014



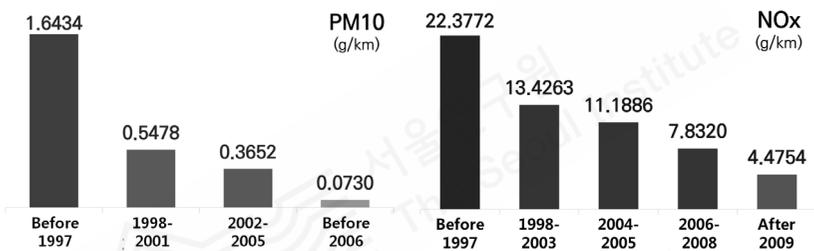
[Figure 1] Share of PM-10 and NOx Emitted by Each Vehicle Type in Total (As of 2012)

This study finds that larger and older cars release more harmful substances into the air. It has been confirmed that specialized vehicles and trucks of large and medium sizes emit more air pollutants than other types of motor vehicles of the same model years. According to this research, trucks of 1996 and 1997 model years discharge 22 times and 2.8 times more of PM-10 and NOx, respectively, than model year 2007 trucks.



(Source: *Report on the Performance of Air Quality Improvement Plan Implementation*, Metropolitan Air Quality Management Office, 2011)

[Figure 2] PM-10 and NOx Emissions from Each Vehicle Type (2007 Model Year Vehicles)



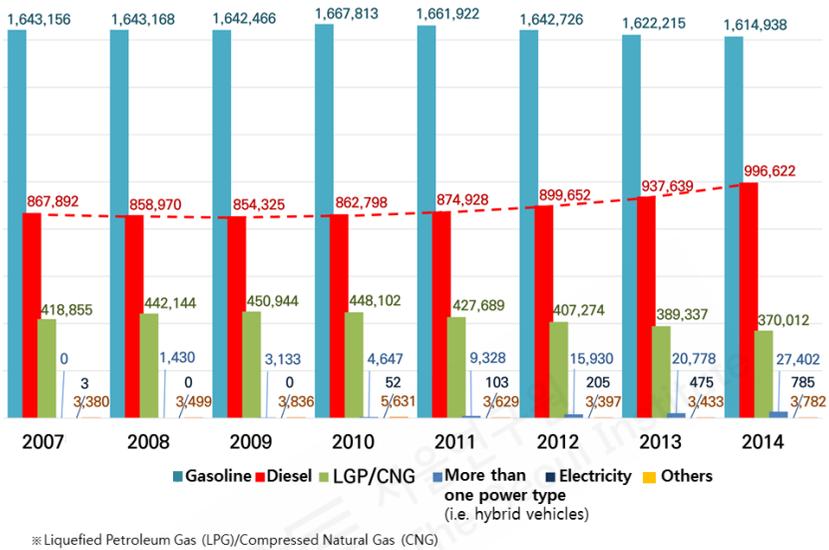
(Source: *Report on the Performance of Air Quality Improvement Plan Implementation*, Metropolitan Air Quality Management Office, 2011)

[Figure 3] PM-10 and NOx Emissions from Large Trucks of Each Model Year

While the number of registered diesel cars in Seoul is increasing, the deterioration of diesel-fueled cars is afoot

Seoul is witnessing a continuous rise in the number of registered motor vehicles. Total registered cars in Seoul (excluding motorcycles) numbered 2,933,286 in 2007, and then reached 3,013,541 in 2014. In particular, the number of diesel-powered cars had increased, representing 33.1 percent of total number of registered cars in Seoul as of 2014 (up from 29.6 percent in 2007). Since the implementation of a five-day workweek, which has raised the popularity of leisure

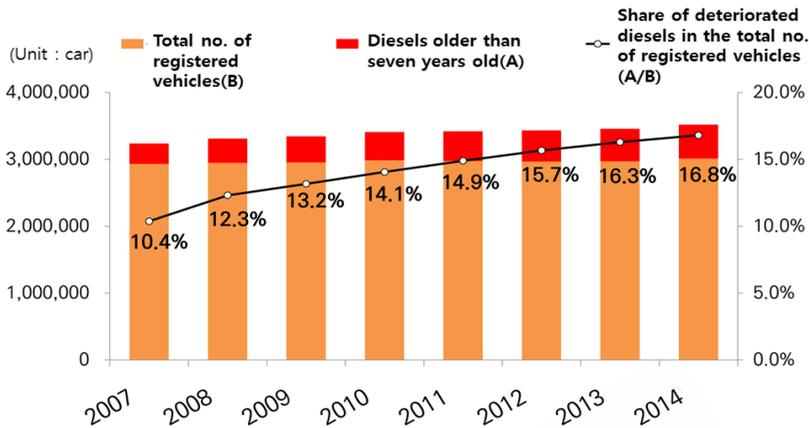
activities across the country, people have increasingly preferred diesel-powered recreational vehicles to others.



Source: Internal Data, The Ministry of Land, Infrastructure and Transport

[Figure 4] Change in the Number of Vehicles of Different Fuel Types in Seoul

The number of decrepit diesel cars that have been over seven years since they were manufactured has grown by 6.4 percent point over the past six years: from 10.4 percent in 2007 to 16.8 percent in 2014. We found that a medium-size van (with the capacity to carry 16-49 passengers) has, on average, 71.6 percent of its components worn-out. A large truck (with the capacity to carry over five ton of cargo), medium RV (of over 2,000cc), and medium truck (with the cargo carrying capacity between one and five ton) each has 70 percent of their components deteriorated. Regardless of the vehicle type, it becomes costly to maintain them as they age. Deteriorated cars also take a toll on environment. As a result, old vehicles form a vicious cycle of aggravating environmental pollution and work as obstacles to the government’s motor vehicle emission control.



[Figure 5] Change in the Share of Deteriorated Cars in Seoul (2007-2014)

The air quality of Seoul can only improve if that of Seoul’s suburbs improve. Therefore, the SMG should work with the Gyeonggi Provincial Government and Incheon Metropolitan City Government, which both have a large number of decrepit diesel cars. The number of old diesel cars in Seoul, Gyeonggi, and Incheon each accounts for 16.8 percent, 25.7 percent, and 18.1 percent of total number of diesels registered in the three areas, respectively. SMG ought to support the Gyeonggi Provincial Government and the Incheon Metropolitan City Government in carrying out their Diesel Emission Control Projects while taking its own measures to control the exhaust gas emission from diesel cars in Seoul. In addition, it needs to control the extra hazardous substances discharged by diesel cars entering and exiting Seoul.

[Table 3] Share of Decrepit Diesel cars in Seoul, Gyeonggi, and Incheon(2014)
(Unit : Car)

Category	No. of Diesels Used for Over 7 Years (A)	Total No. of Registered Diesels (B)	Share of Decrepit Diesels in the Total (A/B)
Seoul	506,435	3,013,541	16.8%
Gyeonggi	985,179	3,838,213	25.7%
Incheon	225,458	1,247,485	18.1%

There exists a palpable difference in the density of auto emissions across vehicles of different models and model years

The density of exhaust gas emitted by a vehicle increases as the vehicle ages (refer to [Figure 6]). This is the case of every car model. This study has discovered that trucks and vans have a relatively high failure rate to pass the emission density test.

The current SMG's Diesel Emission Control Project²² needs to target more diesel-fueled cars heavier than 2.5 ton, considering that they emit a large amount of PM and NOx. Of 481,894 diesel cars registered before 2005, the emission level of 93,823 has been lowered.

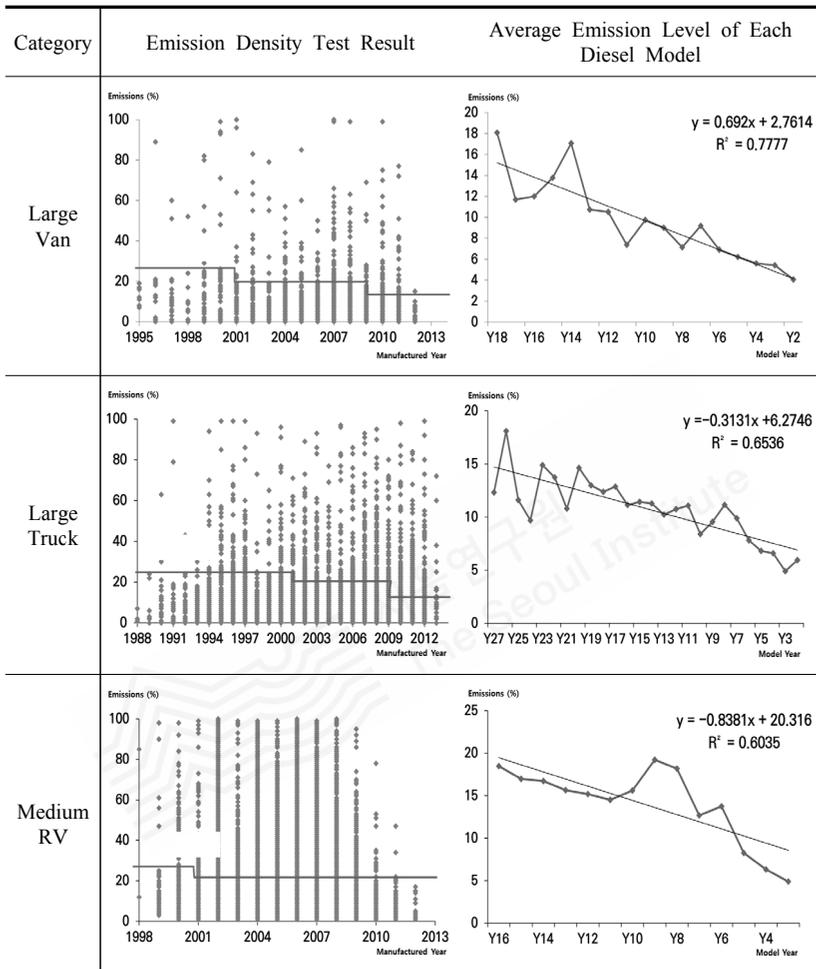
[Table 4] Current Status of the Diesel Emission Control Project (As of 2013)

Category	No. of Registered Diesels (A)	No. of Diesels Completed with the Project (B)	No. of Diesels Not Completed with the Project	Share of Diesels Completed with the Project in the Total (B/A)
Diesels heavier than 2.5t	269,803	27,169	242,634	10%
Diesels lighter than 2.5t	212,091	66,654	145,437	31%
Total	481,894	93,823	388,071	19%

Note : As of 2013, the total number of registered diesels was 937,639. The total number of registered diesels stated in the table (481,894) represents ones registered before 2005. Diesels that have been registered after 2006 number 455,745.

Source : "SMG Will Complete the Diesel Emission Control Project by Late 2019", SMG Press Release (Feb. 26, 2014)

²² SMG's Diesel Emission Control Project aims to protect the health of Seoul citizens from hazardous substances emitted by diesel-fuelled vehicles by installing a Diesel Particulate Filter (DPF), retooling a LPG engine, and inducing the discarding of a decrepit diesel.



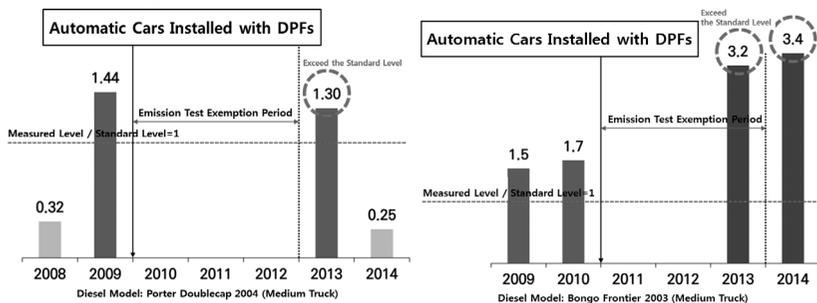
Source: Above measurements are made based on the result of diesel emission test conducted by Korea Transportation Safety Authority in 2014.

[Figure 6] Emission Density Test Result and Average Emission Level of Diesels (Sample Results Based on Certain Car Models and Model Years, as of 2014)

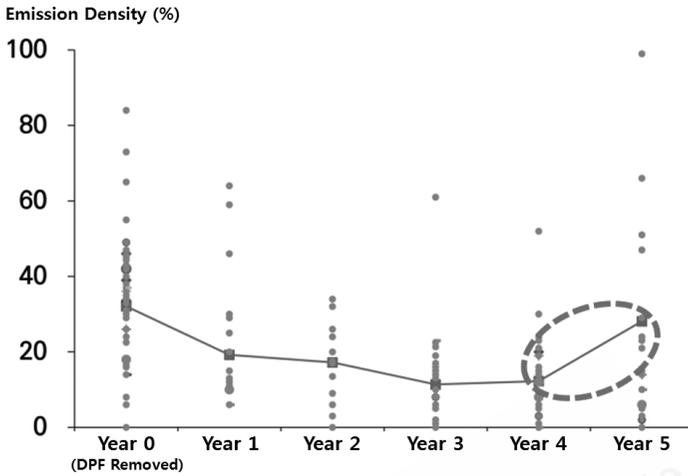
At present, the performance of the Diesel Particulate Filter (DPF) is not up to the expected standard, while the Diesel Emission Control Project does not comprehensively monitor the emission performance of diesel cars

Under the Diesel Emission Control Project, the SMG sets stringent emission standards for diesel-fueled cars whose emission performance warranty period expired. Then it installs a Diesel Particulate Filter (DPF) to diesels that release more auto emissions than the permitted level. SMG also subsidizes the cost of discarding old, pollutant-spewing vehicles.

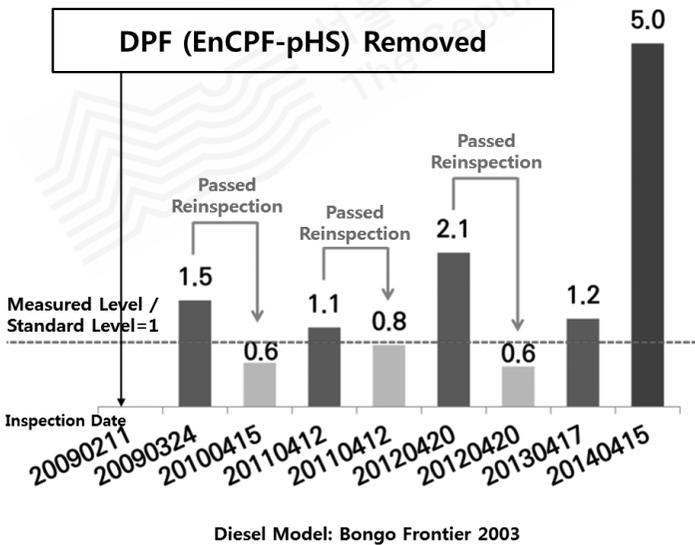
There needs a special management of diesel cars that have been four to five years since DPF installation. According to the study, diesels installed with a DPF release 1.3 ~ 3.4 times more auto emissions than earlier when they reach the fourth year (the three years of emission test exemption period is not counted) since the installation (refer to [Figure 7]). SMG should pay special attention to diesel cars of which the emission density increases by a substantial amount as they reach the fourth or fifth year after DPF installation (refer to [Figure 8]). Diesels discharging more auto emissions than the standard level after a DPF is removed should be managed with special care (refer to [Figure 9]). After installing DPFs to diesels, SMG ought to check their emission density on a regular basis rather than randomly.



[Figure 7] Change in the Emission Density of Diesels after DPF Installation



[Figure 8] Change in the Emission Density of Diesels after DPF Removal



[Figure 9] Cases in Which the Emission Density of Diesels Exceeded the Standard Level after DPF Removal

Some other countries in the world have adopted the hazardous Particulate Matter and Nitrogen Oxide control system, in which diesels are rated according to their emission level and managed accordingly

The Berlin City Government restricts the operation of vehicles that emit an excessive amount of PM. The emission grade is given to cars according to the European (Euro) Emission Standards at the time of vehicle registration. There are three emission grades and the government issues a sticker of red, yellow, and green colors, which are equivalent to Euro Emission Standard Two, Three, and Four, respectively. Vehicles of the Euro Emission Standard One are not given any sticker as their emissions exceed the standard level.

[Table 5] The Emission Rating System of Berlin City Government

Sign	Euro Emission Standard	Emission Grade	Engine Type	First Registration Date (Passenger Car)	First Registration Date (Truck)
None	Euro 1	1		Before Jan. 1, 1997	Before Oct. 1, 1996
	Euro 2 Euro 1 + filter	2		Jan. 1, 1997- Dec. 31, 2000	Oct. 1, 1996- Sep. 30, 2001
	Euro 3 Euro 2 + filter	3	Diesel	Jan. 1, 2001- Dec. 31, 2005	Oct. 1, 2001- Sep. 30, 2006
	Euro 4 Euro 3 + filter	4		After Jan. 1, 2006	After Oct. 1, 2006
None	Lower than Euro 1	4		Before Jan. 1, 1993	Before Jan. 1, 1993
	Higher than Euro 1	5	Gasoline	After Jan. 1, 1993	After Jan. 1, 1993

Source : Berlin's Environmental Zone Information for Foreign Tourist.

France will be implementing the emission rating system in which it will issue an environmental label called a “CRIT’air Label.” Different labels will be given to vehicles according to the level of their PM, Carbon Monoxide, and Hydrocarbon emissions. From 2016, district offices will be autonomously using the rating system to restrict pollutant-spewing cars from driving.

[Table 6] CRIT’air Labeling System of France

Sign	Euro Emission Standard	Qualification
		100% electric cars Benefit: Allow free parking by the roadside and driving at no passing zones
	Euro 5 & 6	Gasoline-fuelled cars registered after January, 2011
	Euro 4	Gasoline-fuelled cars registered between 2006-2010
	Euro 5 & 6	Diesels registered after January, 2011
	Euro 2 & 3	Gasoline-fuelled cars registered between 1997-2005
	Euro 4	Diesels registered between 2006-2010
	Euro 3	Diesels registered between 2001-2005
	Euro 2	Diesels registered between 1997-2000
	Euro 1	Gasoline-fuelled cars and diesels registered before 1997

Source : Press release (Jun.4, 2015), The Ministry of Ecology, Sustainable Development and Energy, France

The city government of Paris has categorized vehicles registered in the city into four types (refer to [Table 7]), and is planning to gradually disallow their operation in the city by 2020. Until the enactment of the Energy Conversion Act, the city of Paris will be issuing a warning to vehicles that violate the emission regulation. Upon the enactment, it will charge them a penalty (22 euro).

[Table 7] Vehicle Categorization System of Paris

Category	Passenger Car, Small Truck	Motorcycle	Trucks, City Bus, Tour Bus
Grade 1	Gasoline & Diesel (Euro 1), registered before Jan. 1, 1997	(Euro 1), registered before Jan. 1, 2000)	Gasoline & Diesel (Euro 2), registered before Jan. 1, 2001)
Grade 2	Diesel (Euro 2), registered before Jan. 1, 2001	Smaller than 50cc (Euro 2) & Larger than 50cc (Euro 1), registered before Jan. 1, 2004)	Diesel (Euro 3), registered before Jan. 1, 2006)
Grade 3	Diesel (Euro 3), registered before Jan. 1, 2006)	Smaller than 50cc (Euro 2) & Larger than 50cc (Euro 1), registered before Jul. 1, 2015)	-
Grade 4	Diesel (Euro 4). registered before Jan. 1, 2011)	-	Gasoline & Diesel (Euro 4), registered before Jan. 1, 2009

Source : "France's CRIT'air, Unfavorable System to Diesels," KOTRA Foreign Business Information Portal, KOTRA (2015)

In order to control the excessive auto emissions of diesel cars, a rigorous emission test should be carried out with stringent emission standards

This research has found that each country has their own emission test methods and standards: The US runs the Inspection and Maintenance (I/M) Program, and the California state, in particular, has implemented its own program called Smog Check Program; Vancouver, Canada has the Air Care Program; Australia runs IM240·

DT80; and Japan, Germany, and China all have implemented Vehicle Mass Analysis System (VMAS).

Some countries and cities are utilizing Remote Sensing Devices (RSDs) to supplement their emission tests. In detail, the RSDs are used to screen vehicles with very clean emissions (clean screening) and identify vehicles that release an excess of air pollutants (gross emitter identification). They continue to collect and analyze emission data for assessing the emission characteristics of diesel cars. Such an action is necessary to prove the validity and effectiveness of emission policies, and developing other policies for transportation and the environment protection.

3. Conclusions & Policy Recommendations

SMG should take the lead in controlling diesel cars that emit an excess of PM and NOx

It is necessary for the SMG to set the “Excessive Emission Standards” to assess the emission performance of diesel-powered vehicles. At present, the diesel emission test measures auto emissions of diesels in terms of density. Therefore, it is difficult to use the test results in checking the excess emission level relative to the permitted level. SMG should develop a rating system for diesel cars that release more emissions than the permitted level. The system needs to score such diesels by factoring in the amount of emissions larger than the standard level. Next it should calculate the total scores for excess emission by adding weighted points based on the assessment criteria of the Clean Air Policy Support System (CAPSS). Based on the total excess emission scores, the SMG needs to rate diesel cars on the grade scale of one to five (level one is given to diesels releasing the most excessive amount of auto emissions).

01. Assessment Subjects

Categorize assessment subjects

- Categorize vehicles according to the vehicle model classification standards of the Automobile Management Act
 - Passenger car (standard, one for both passenger use and freight, multi-purpose, others)
 - Van (standard, specialized type)
 - Truck (standard, dumping, van, special-purpose)
 - Specialized vehicle (tow vehicle, rescue vehicle, special-function)
- Categorize according to the CAPSS standards
 - Passenger car, van, truck, specialized vehicle, RV



02. Assessment Criteria

Revise the assessment criteria for excess emission rating

- No. of diesels emitting more hazardous substances than the permitted level, No. of diesels assessed → % of diesels discharging an excess of emissions
- Emission density exceeding the permitted level, Emission density → % of emission density higher than the permitted level
- Emission level per unit (emission coefficient x distance travelled per annum) → a weighting to be given to diesels discharging an excess of emissions

03. Assessment Methods

Check the excess emission rating score distribution

$$G=f(A, B, C)$$

- A = % of diesels discharging an excess of emissions
- B = % of emission density higher than the permitted level
- C = a weighting to be given to diesels discharging an excess of emissions

Excess emission %	0~10%	10~20%	20~30%	30~40%	40~50%	50~60%	60~70%	70~80%	80~90%	90~100%
A, B scores	1	2	3	4	5	6	7	8	9	10

04. Rating

Rate diesels according to their total excess emission scores

- Compile statistics on excess emission and analyze them
- Rate diesels on the grade scale of one (most excessive) to five (least excessive)

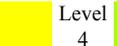
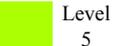
[Figure 10] Process of Rating Diesels for Excess Emission

There needs a customized control mechanism for diesel-powered vehicles rated with high excess emission grades

This study has found that large trucks are given either level one or two excess emission grades, discharging more hazardous substances than any other types of vehicles. In particular, large trucks of model year before 2005 emit an excess of PM. SMG should evaluate the excess emission grades of diesel cars based on the results of emission test that Korean Transportation Safety Authority has conducted to cars registered in 2014. It is estimated that medium trucks, specialized trucks, dump trucks, and specialized vehicles (rescue cars and tow cars) release an excessive amount of PM given their level one and two excess emission grades.

[Table 9] Excessive Emission Rating Score Distribution among Diesels Driving in Seoul

Category	Before 1995	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Small passenger car	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Medium passenger car	X	X	X	X	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Large passenger car	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Small van	3	3	3	3	X	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Medium van	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Large van	X	X	3	3	3	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Specialized van	X	X	X	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Small truck	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Medium truck	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Large truck	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Specialized truck	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Dump truck	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Specialized vehicle - rescue car	3	X	X	X	X	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Specialized vehicle - tow car	3	3	3	3	X	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Specialized vehicle - other	3	3	X	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Small RV	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Medium RV	X	X	X	X	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Excess emission grade :  Level 1  Level 2  Level 3  Level 4  Level 5

Local governments can implement the emission control system tailored for each type of vehicle only if the excess emission rating system is available

The national government should be in charge of emission rating of new cars, while local authorities should take the responsibility for controlling the excessive emission of vehicles already operating in their areas. To successfully implement the excessive emission rating system, local governments must build their capacities in identifying cars that should be placed under the Diesel Emission Control Project, carrying out the auto emission inspection and maintenance (I/M), and operating low emission zones (LEZs).

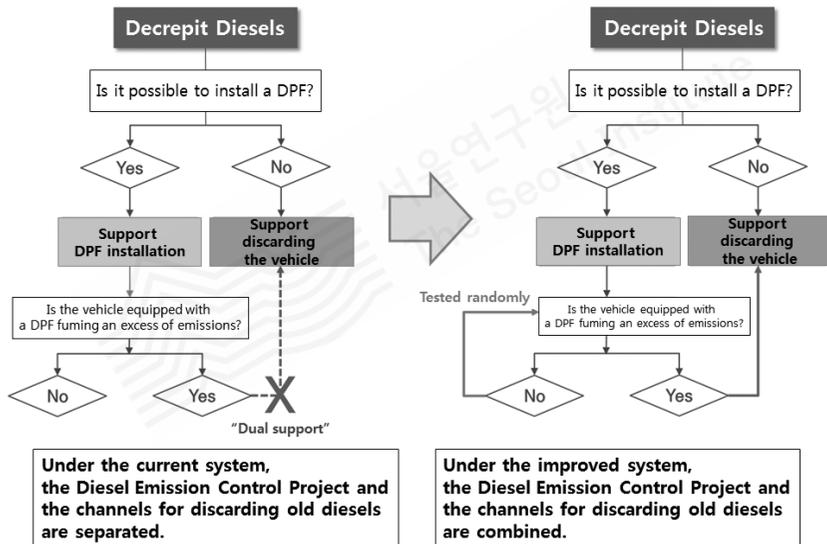
SMG should set the priorities for the Diesel Emission Control Project pursuant to the excess emission grades of vehicles. While large trucks of every model year are assessed to emit a highly excessive amount of air pollutants, the Diesel Emission Control Project (the DPF installation and engine retooling) primarily targets small and medium trucks at present. SMG should address this problem. It needs to pay attention to specialized vehicles (rescue cars and tow cars) that are rated with high excess emission grades, yet have no DPF specifically designed for them.

SMG should control the emission performance of diesel cars by applying different emission control standards and methods in each stage of their “life cycle”

In each stage of managing the emission performance, the government, vehicle owners, and auto manufacturers should play their given roles. Based on the excess emission rating results, the SMG needs to select vehicles for the Diesel Emission Control Project. Due to the emission test exemption period (three years) applied to diesel cars upon the installation of DPFs, the SMG cannot measure their auto emissions for a certain length of time. In addition, while the SMG often evaluates the emission performance of intra-city and shuttle buses, it does not assess that of trucks and passenger cars. As a result, it is difficult to ensure that DPFs installed in

non-tested vehicles perform up to the expectation. SMG should set the priorities for the Diesel Emission Control Project by comparing first, the amount of emissions released by vehicles before and after the emission performance warranty period, and second, the emission level of vehicles of each model and manufactured year.

At the same time, the SMG should establish a one-track support system by combining the current Diesel Emission Control Project and the channels for scrapping battered diesels. With the one-track support system based on the excess emission rating results, the SMG would be able to check the feasibility of installing DPFs and the excess emission level of vehicles.



[Figure 11] Diesel Emission Control Project Combined with Channels for Discarding Decrepit Diesels

SMG should connect the LEZ management with the excess emission rating system

SMG needs to restrict vehicles that release an excess of hazardous substances beyond the permitted level in the Low Emission Zone (LEZ). It should be stipulated in the related legislation. In particular, the SMG should urge vehicles carrying children

that are rated with high excess high emission grades to stop operating in the zone.

Incentives need to be offered to induce the owners of old, emission-spewing diesel cars to scrap their cars

SMG should institute an incentive system to induce the disposal of deteriorated vehicles. Although it is most efficient to make the owners of diesel cars rated with high excess emission grades to discard their vehicles, the current decrepit vehicle disposal inducement system does not admonish them to do so. In this regard, the SMG should subsidize the cost of discarding old, pollutant-spewing cars. The amount of financial incentive should be set by weighing the model and manufactured year of the vehicle and its excess emission levels. In addition, the SMG ought to identify low-income families owning vehicles emitting an excess of air pollutants. As an attempt to alleviate the burden of purchasing a new car (that qualifies the Euro Emission Standards Three and Four), the SMG may offer them subsidies or tax benefits to cover the cost of disposing their previous cars and buying new ones.

SMG ought to improve the vehicle emission test and ensure its reliability

SMG should improve the assessment criteria of vehicle emission test. The current emission test only examines the level of PM emitted by a diesel car and, depending on the level, the SMG decides whether the vehicle passes or fails the test. This study shows that adjusting the fuel injector or Exhaust Gas Recirculation (EGR) device of a diesel car to reduce its emissions cannot be a solution: It decreases the PM emissions, yet substantially increases NOx emissions, raising the density of NO2. SMG should set the emission standards for NOx and NO2 emissions of diesel cars, and add such standards to the vehicle emission inspection. In accordance with the emission standards, the SMG needs to draw a plan to manage

the performance of NO_x measurement devices.

At the same time, the SMG should ensure the effectiveness of diesel emission test. According to a recent test, the proportion of vehicles releasing excess auto emissions was 7.2 percent and 9.5 percent in 2013 and 2014, respectively. To ensure the reliability and relevance of test results, SMG should carry out the test on a regular basis. Moreover, the SMG needs to implement On-Board Diagnostics (OBD) and the vehicle emission inspection system for diesel cars that satisfy the criteria above the Euro Emission Standard Four. In addition, it should consider carrying out a performance inspection for OBD II category in testing the emission performance (including NO_x and PM emission) in the future.

SMG needs to keep vehicle emission data in a database, while building governance in which it can collaborate with the national government, auto manufacturers and Seoul citizens

SMG should establish a database for the efficient management of PM and NO_x emissions. The database should contain data that show the emission characteristics of vehicles, vehicles registered in Seoul (assorted by a model and a manufactured year), and the distance travelled, emission level, emission test result, and modification information of vehicles. Excess emission rating results should also be collected and kept in the database. SMG should utilize the data in establishing a customized management plan containing the emission characteristics of vehicles, and the environmental grade of vehicles.

There should be established governance in which the SMG, the national government, citizens, and car manufacturers can work together for vehicle emission control. The national government needs to provide SMG with legal and institutional support so that it can build the capacity necessary for controlling the PM and NO_x emission from vehicles driving in Seoul. In detail, the SMG must ensure that the diesel emission test inspects NO_x and NO₂ emissions as well as PM emissions of

vehicles. This means that the government should add NOx emission standards and assessment criteria for diesels with implementing the OBD monitoring test and the I/M test.

SMG, on the other hand, needs to adopt a differentiated management plan for each excess emission level, while encouraging vehicle owners to reduce auto emissions by paying them financial incentives. At the moment, the SMG subsidizes the cleaning cost. Taking a step further, it should foster and support social organizations advocating environmental protection. SMG needs to consider financially supporting car owners with emission test by connecting the test with the vehicle eco-mileage program.

Meanwhile, Seoul citizens should participate in improving the city's air quality by making necessary improvements to the emission performance of their cars. They need to engage in the vehicle eco-mileage program.

Lastly, auto manufacturers should provide services for the emission diagnosis of vehicles, as well as for old component exchange and repair. This way, they can take their parts in discarding decrepit vehicles spewing an excess of pollutants.