

Technical Information

Analysis of the National Air Pollutant Emission Inventory (CAPSS 2016) and the Major Cause of Change in Republic of Korea

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ABSTRACT In 2016, air pollutant emissions in the Republic of Korea were 795,044 metric tons (hereafter tons) of CO, 1,248,309 tons of NO_x, 358,951 tons of SO_x, 611,539 tons of TSP, 233,085 tons of PM₁₀, 100,247 tons of PM_{2.5}, 16,401 tons of BC, 1,024,029 tons of VOCs, and 301,301 tons of NH₃. Including energy production, thirteen emission sources, which comprise the national air pollutant emission inventory, were classified by their characteristics into five sectors (Energy, Industry, Road, Non-road, and Everyday Activities and Other Emission Sources) to analyze their relative contributions to the national emissions. Specifically, their contributions by pollutant were as follows: NO_x (11.0%), SO_x (21.9%), PM_{2.5} (3.2%), VOCs (0.8%), NH₃ (0.5%) from the energy sector; NO_x (20.2%), SO_x (59.7%), PM_{2.5} (42.1%), VOCs (24.3%), and NH₃ (14.4%) from the industry sector; NO_x (36.3%), SO_x (0.1%), PM_{2.5} (9.7%), VOCs (4.6%), and NH₃ (1.7%) from the road sector; NO_x (24.8%), SO_x (11.5%), PM_{2.5} (14.3%), VOCs (4.0%), and NH₃ (0.04%) from the non-road sector; and NO_x (7.6%), SO_x (6.7%), PM_{2.5} (30.6%), VOCs (66.3%), and NH₃ (83.4%) from the everyday activities and other emission sources sector. The data we calculate are used as official national emissions data for the establishment, implementation, and assessment of national atmospheric environment policy to improve air quality. As critical and necessary materials, the data are also utilized on a wide range of studies on policies such as customized regional particulate matter reduction measures. Thus, it is crucial to estimate highly reliable national emissions by enhancing the emissions factors and inventory and to establish a scientific emissions testing system by using air quality modeling and satellite data.

KEY WORDS CAPSS, Atmospheric pollutants, Particulate matter, Ultrafine particulate matter, National air pollutant emissions

1. INTRODUCTION

Air pollution, including particle pollution is becoming a serious issue worldwide. To be more specific, industrialization has led the world population, traffic, and energy consumption to increase, which is consequently exacerbating air quality. Furthermore, transboundary air pollutants are having an adverse effect not only on polluting countries but also on their neighboring ones (Li *et al.*, 2014). This makes it clear that air pollution arising from such pollutants must be tackled from a global perspective. To improve air quality, Southeastern Asian countries such as South

Korea, China, and Japan, are implementing a wide range of policies, which include energy efficiency improvement and reduction of air pollutants emissions (Wang *et al.*, 2014).

Estimating air pollutant emissions data is vital for informing policy and research to improve the atmospheric environment. However, it is a delicate issue due to the various politico-economic interests involved. Nevertheless, these data are needed to establish policies for atmosphere management and to counter climate change and are an important tool for policy setting and outcome assessment.

Looking at the state of emissions in major developed countries, in the United States, the Environmental Protection Agency (EPA) compiles and publishes the National Emission Inventory (NEI), focusing on general air pollutants and hazardous air pollutants (HAPs). Meanwhile, in the European Union, its member states are asked to submit their own emissions data on CO₂, CH₄, N₂O, SO₂, NO_x, CO, NMVOC, PFCs, and SF₆, which are maintained and released by the European Environment Agency (EEA). Most of the members use the standardized CORINAIR system.

In the Republic of Korea, the National Air Emission Inventory and Research Center (hereafter “the NAIR”) estimates the annual emissions of the air pollutants, CO, NO_x, SO_x, TSP, PM₁₀, PM_{2.5}, BC, VOCs, and NH₃, via the Clean Air Policy Support System (CAPSS). To this end, around 300 data points are collected from 150 domestic institutions (as of 2016 emissions). Emissions are calculated by applying the emissions factors and control efficiency for each emission source/fuel to the appropriate activity level for each emission source.

The estimated emissions play the role of the official air pollutants emissions data for the Republic of Korea, which are then used as the basis to establish and analyze the expected effects of policies for air improvement, such as the combined air improvement plan, the basic plan for atmospheric environment management in the capital, special measures against particulate matter, and combined measures to control particular matter. It is also used as input data for air quality prediction models. Thus, alongside air pollution monitoring network data, emissions data are the most important basic data.

In addition, the data are used in the Korean version of Greenhouse Gas - Air pollution Interaction and Synergies (GAINS), an integrated analysis model for climate and air which is widely used in various studies in Europe

and Asia (Seong *et al.*, 2019), and also used in building an emission inventory of Southeast Asia, which were cited from the KORUS-AQ (Korea-United States Air Quality) study, a joint research project conducted by the National Institute of Environmental Research in Korea and the National Aeronautics and Space Administration (Choi *et al.*, 2019; Goldberg *et al.*, 2019; Miyazaki *et al.*, 2019).

In this report, we describe the results of 2016 emissions estimates and analyze the major factors contributing to changes from 2015.

2. METHODS OF ESTIMATION NATIONAL AIR POLLUTANT EMISSIONS

2.1 Emission Source Classification and Emission Factors

To estimate national air pollutant emissions data, we established an emission source classification system by combining the CORINAIR classification system from Europe with the domestic industrial classification system for air pollutant emission sources. Thus, we classified emission sources into thirteen categories including energy production, non-industry, manufacturing industry, industrial processes, energy transport and storage, solvent use, road transport, nonroad transport, waste, agriculture, other, fugitive dust, and biomass burning. These categories were further classified into 57 subcategories, which were further categorized into 241 subgroups to estimate emissions of CO, NO_x, SO_x, TSP, PM₁₀, PM_{2.5}, BC, VOC, and NH₃.

Emission factors are displayed as emissions per unit activity. Currently, approximately 30,000 emission factors are used in the national emissions estimate. Incidentally, while emission factors developed from research by domestic scientific research institutes such as the National Institute of Environmental Research are primarily used in the estimate, in most cases, the factors from the US EPA and the EU CORINAIR are used except for a couple of emission sources including vehicles, construction machineries, and combustion facilities (NIER, 2015).

2.2 Method for Activity Level and Emission Estimation

To estimate national air pollutant emissions, we det-

etermined the basic activity level after collecting 300 sets of statistics from approximately 150 institutions related to energy, industry, transport, and meteorology. There are usually three ways to validate those data: comparing the totals of raw data and registered data on the database to identify errors which might have happened when registering data in the first place; studying the previous results regarding the newly collected data and analyzing changes compared to the previous year; and comparing with other similar data.

Based on these basic data established, emissions from each emission source were calculated by applying different calculation methods to different sources. Generally, two approaches were taken to estimate emissions depending on the type of emission source: a bottom-up approach and a top-down approach.

Emissions from point pollution sources were estimated using a bottom-up approach based on data collected from the Stack Emission Management System (SEMS). On the other hand, those from area sources were estimated using a top-down approach based on national statistics on fuel regarding the amount of fuel sales and LNG supply, and coal consumption except for fuel consumed in point pollution sources. Emissions from transport were also estimated by using the top-down approach based on statistics on traffic volume. Incidentally, emission factors by pollutant were taken into account in those estimates. A spatial allocation model was then used for the estimated emissions and regional emissions were estimated based on factors such as SEMS coordinates and addresses for industrial sites and traffic volume for transport, respectively (NIER, 2013).

To perform quality assurance and quality control (QA/QC) activities, the NAIR publishes a standard operating procedure (SOP) guide, which covers each stage ranging from collection of activity level data needed to estimate national emissions to validation of them, a handbook on methods for emission estimation, and an information package on emission factors. Arguably, this is necessary to ensure that the estimation methods are consistent and universal and to enhance reliability of the emission inventory (NIER, 2019a).

2.3 Record of Major Improvements in Emissions

The methodology for estimating air pollutant emissions was reviewed by the National Emissions Data Management Committee of the NAIR based on relevant domestic and overseas research results. Further-

more, past emissions were re-estimated using the latest methodology in the event of major changes in emissions due to the addition of new substances or the discovery of new emission sources in order to ensure the consistency of emission trends analysis. To estimate the national emissions in 2016 in a more accurate manner, several improvements were made to the estimation methods. For example, new PM emissions factors for vehicles on gasoline and LPG multi-point injection (MPI) engines were applied to estimate road transport emissions. Also, new PM emissions factors for two-wheeled vehicles (with four-stroke engines) were applied, and NO_x and NH₃ emissions factors for small diesel vehicles (Euro 3 and Euro 4 emission standards) were updated to the present 2016 COPERT emission factors. Moreover, new emissions factors for CO, HC, NO_x, PM, NH₃, and SO_x for hybrid vehicles and NO_x emissions factors for such diesel vehicles as passenger cars, RVs, freight cars, special cars, and buses (before Euro 3 emission standards), which reflected the actual road driving conditions, were applied as well. When it came to non-road transport emissions, emissions factors for CO, HC, NO_x, and PM for construction machineries (2015 model year onwards) reflecting the Tier 4 emission standards were applied.

3. 2016 EMISSIONS ESTIMATES

3.1 Air Pollutant Emissions

3.1.1 Emissions per Substance and Emission Source

In 2016, the nationwide emissions of air pollutants included 795,044 tons of CO, 1,248,309 tons of NO_x, 358,951 tons of SO_x, 611,539 tons of TSP, 233,085 tons of PM₁₀, 100,247 tons of PM_{2.5}, 16,401 tons of BC, 1,024,029 tons of VOCs, and 301,301 tons of NH₃ (Table 1) (NIER, 2019b).

The main emission sources' proportion of total emissions per pollutant were as follows: road transport (30.8%), biomass burning (29.3%), and non-road transport (17.2%) for CO; road transport (36.3%), non-road transport (24.8%), and manufacturing industry (14.0%) for NO_x; industrial processes (31.4%), energy production (25.5%), and manufacturing industry (24.1%) for SO_x; fugitive dust (67.5%) and manufacturing industry (20.1%) for TSP; fugitive dust (46.2%) and manufacturing industry (30.8%) for PM₁₀; manufacturing industry

Table 1. 2016 emissions and the relative contribution of air pollutants per major emission source category. (units: tons/year)

Source category	CO	NO _x	SO _x	TSP	PM ₁₀	PM _{2.5}	BC	VOC	NH ₃
Total	795,044 (100%)	1,248,309 (100%)	358,951 (100%)	611,539 (100%)	233,085 (100%)	100,247 (100%)	16,401 100%	1,024,029 (100%)	301,301 (100%)
Energy production	58,579 (7.4%)	145,445 (11.7%)	91,696 (25.5%)	4,273 (0.7%)	3,951 (1.7%)	3,253 (3.2%)	330 (2.0%)	8,001 (0.8%)	1,559 (0.5%)
Non industry	67,735 (8.5%)	85,824 (6.9%)	24,015 (6.7%)	1,694 (0.3%)	1,468 (0.6%)	978 (1.0%)	161 (1.0%)	2,740 (0.3%)	1,415 (0.5%)
Manufacturing industry	18,170 (2.3%)	175,332 (14.0%)	86,593 (24.1%)	123,138 (20.1%)	71,794 (30.8%)	36,785 (36.7%)	776 (4.7%)	3,342 (0.3%)	672 (0.2%)
Industrial processes	27,340 (3.4%)	55,932 (4.5%)	112,734 (31.4%)	12,056 (2.0%)	6,731 (2.9%)	5,191 (5.2%)	17 (0.1%)	186,104 (18.2%)	42,489 (14.1%)
Energy transport and storage								30,160 (2.9%)	
Solvent use								558,004 (54.5%)	
Road transport	244,556 (30.8%)	452,995 (36.3%)	231 (0.1%)	10,596 (1.7%)	10,596 (4.5%)	9,748 (9.7%)	5,930 (36.2%)	47,561 (4.6%)	5,071 (1.7%)
Non-road transport	136,612 (17.2%)	309,986 (24.8%)	41,443 (11.5%)	15,592 (2.5%)	15,588 (6.7%)	14,354 (14.3%)	6,781 (41.3%)	40,816 (4.0%)	117 (0.04%)
Waste	2,008 (0.3%)	13,570 (1.1%)	2,161 (0.6%)	406 (0.1%)	295 (0.1%)	252 (0.3%)	4 (0.02%)	58,988 (5.8%)	22 (0.01%)
Agriculture									237,017 (78.7%)
Other	6,977 (0.9%)	167 (0.01%)		481 (0.1%)	306 (0.1%)	275 (0.3%)	14 (0.1%)	624 (0.1%)	12,924 (4.3%)
Fugitive dust				412,686 (67.5%)	107,735 (46.2%)	17,286 (17.2%)	115 (0.7%)		
Biomass burning	233,066 (29.3%)	9,059 (0.7%)	78 (0.02%)	30,618 (5.0%)	14,623 (6.3%)	12,124 (12.1%)	2,274 (13.9%)	87,687 (8.6%)	15 (0.01%)

*BC: BC(Black Carbon) as EC(Elemental Carbon)

(36.7%), fugitive dust (17.2%), and non-road transport (14.3%) for PM_{2.5}; non-road transport (41.3%) and road transport (36.2%) for BC; solvent use (54.5%) and industrial processes (18.2%) for VOCs; and agriculture (78.7%) and industrial processes (14.1%) for NH₃ (Fig. 1).

3.1.2 Analysis on Changes in Emissions compared to the Previous Year

On an annual basis, the OECD (Organization for Economic Cooperation and Development) asks its member states to submit national emissions estimates for CO, NO_x, SO_x, PM₁₀, PM_{2.5} and NMVOC (Non-methane

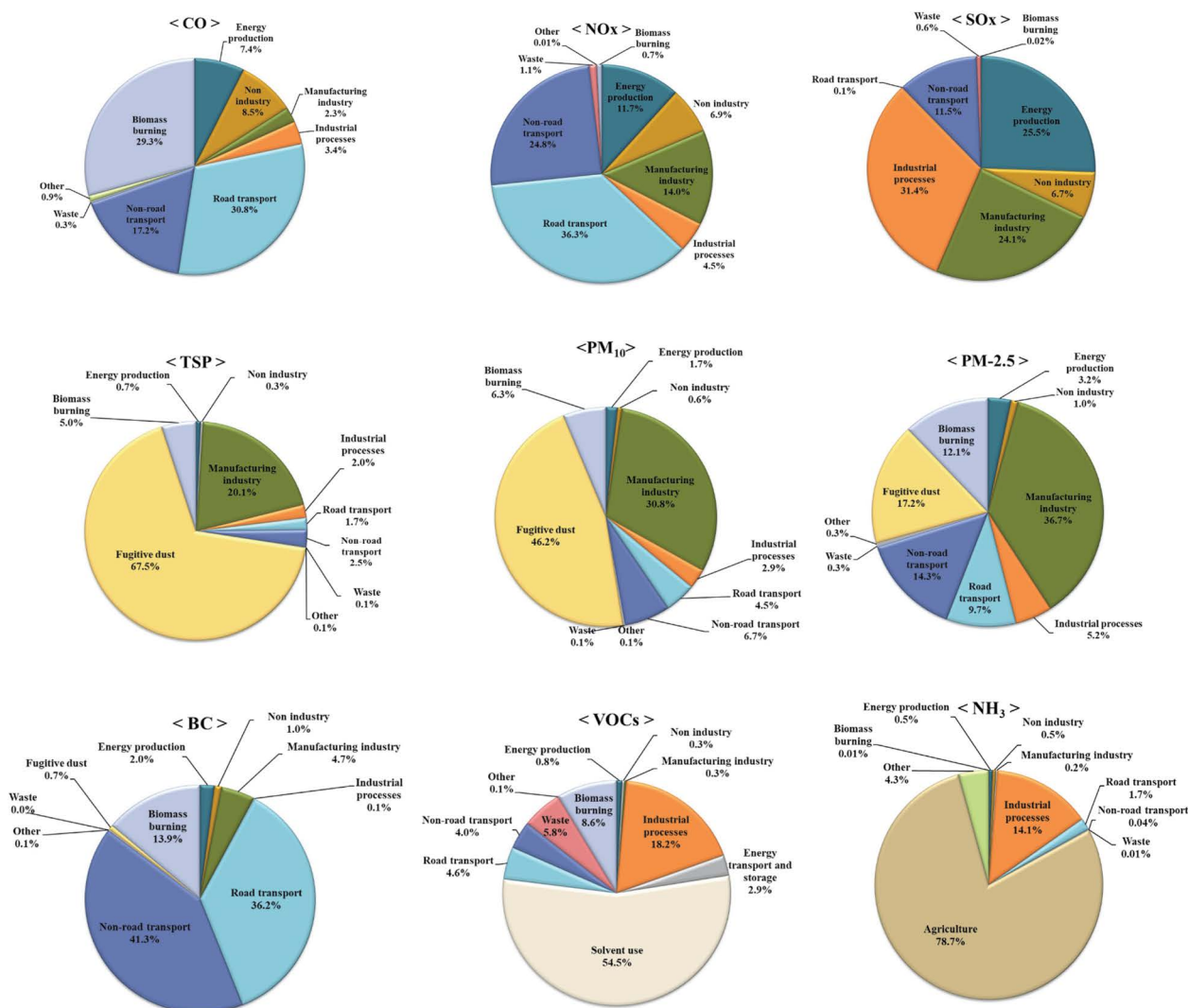


Fig. 1. 2016 emission contributions of different emission source categories, per pollutant.

Volatile Organic Compounds) from mobile and stationary sources, collects and makes the data public (<https://stats.oecd.org/>).

Republic of Korea also submits its national emissions estimates based on the CAPSS annually. However, a few emission sources on the domestic classification system are not included in the OECD submission criteria, resulting in gaps between the annual total national emissions estimates and those submitted to the OECD.

Table 2 represents national air pollutant emissions for the OECD member states. According to the OECD, Canada saw a 4.4% decrease in NMVOCs emissions while SO_x emissions dropped in the UK (-28.4%), the US (-19.1%), France (-11.7%), and Germany (-7.3%),

respectively. Meanwhile, PM_{2.5} emissions in Republic of Korea and CO emissions in Japan increased by 2.4% and 10.9%, respectively while PM₁₀ and PM_{2.5} emissions estimates in Japan were not provided with.

3.1.3 Analysis on Changes in Emissions Compared to the Previous Year

Although air pollutant emissions have been estimated since 1999, directly comparing with past data is difficult due to annual additions of new emission sources or improvements in estimation methods as mentioned above. Since 2007, anthracite coal imports have been added to the emissions estimate, CleanSYS emissions data have been used, and the VOCs' emission factors

Table 2. National air pollutant emissions for the OECD member states.

	(unit: 1,000 tons/year)																	
	CO			NO _x			SO _x			PM ₁₀			PM _{2.5}			NMVOCs		
	2015	2016	Change	2015	2016	Change	2015	2016	Change	2015	2016	Change	2015	2016	Change	2015	2016	Change
Canada	5,733.0	5,682.7	-0.9%	1,774.6	1,714.6	-3.4%	1,068.4	1,052.7	-1.5%	8,503.8	8,550.0	0.5%	1,595.4	1,594.9	-0.03%	1,930.1	1,844.6	-4.4%
France	2,665.3	2,698.0	1.2%	867.4	824.4	-5.0%	159.2	140.6	-11.7%	230.0	229.9	-0.1%	149.5	149.2	-0.2%	633.9	617.5	-2.6%
Germany	3,175.1	3,036.3	-4.4%	1,364.1	1,333.1	-2.3%	335.8	311.2	-7.3%	219.0	204.0	-6.9%	105.6	99.6	-5.7%	1,166.1	1,160.0	-0.5%
Japan	2,507.2	2,779.4	10.9%	1,302.2	1,421.7	9.2%	701.7	700.9	-0.1%	-	-	-	-	-	-	905.0	905.7	0.1%
Republic of Korea	714.9	718.3	0.5%	1,154.8	1,245.4	7.8%	352.2	358.9	1.9%	146.3	150.1	2.6%	84.3	86.3	2.4%	960.9	973.4	1.3%
United Kingdom	1,692.7	1,562.2	-7.7%	1,006.4	916.4	-8.9%	249.9	178.8	-28.4%	167.4	169.7	1.4%	107.6	106.3	-1.2%	799.1	784.7	-1.8%
United States	48,107.5	43,924.2	-8.7%	10,641.4	10,152.7	-4.6%	3,514.1	2,841.9	-19.1%	14,950.9	14,319.8	-4.2%	3,940.0	3,786.7	-3.9%	12,577.0	11,786.7	-6.3%

Table 3. Emission source classification by sector and category.

Source sector	Source category
Energy (Oil refinery not included)	Energy production
Industry (Oil refinery included)	Manufacturing industry Industrial processes Waste Oil refinery
Road	Road transport
Non-road	Non-road transport
Everyday activities and other emission sources	Non industry Energy transport and storage Solvent use Agriculture Other Fugitive dust Biomass burning

have been changed, resulting in large shifts in emissions for the related substances. In 2011, improvements to emission estimates continued to be pursued, with the addition of PM_{2.5} emissions and new emission sources such as industrial processes, improvement of the car emission factors for transport, and use of control efficiency of oil mist collection facilities in the energy transport and storage category. In 2012, the estimation methodology was improved in the non-road transport (construction machinery) category, and the activity levels of the food and drinks manufacturing (whiskey and other spirits) and VOCs emission factors were improved. In 2014, fishing vessels and leisure boats were added to the ships category, and the methodology for the road sector was also improved, such as using NO_x emissions factors that reflected the actual road driving conditions. In 2016, NO_x emissions factors for diesel vehicles (before Euro 3 emission standards) were improved by reflecting the actual road driving conditions, and PM emissions factors for MPI gasoline and LPG vehicles were introduced based on research findings.

In this report, the main causes of change in emissions from 2015 to 2016 are analyzed and described by classifying emission sources into five sectors such as Energy, Industry, Road, Non-road, and Everyday Activities and Other Emission Sources based on NO_x, SO_x, VOCs and NH₃ contributing to the formation of primary and secondary PM_{2.5}, as shown in Table 3. Further details on

Table 4. Changes in emissions and percentage in the energy sector by pollutant. (units: tons/year)

Source sector	Pollutant	Emissions		Change (Emissions)	Change (Percentage)
		2015	2016		
Energy	NO _x	143,000	137,744	-5,256	-3.7%
	SO _x	78,838	78,779	-59	-0.1%
	PM _{2.5}	3,584	3,230	-354	-9.9%
	VOCs	7,137	7,706	+242	+3.4%
	NH ₃	1,181	1,382	+201	+17.0%

emissions per pollutant by emission source can be found in Appendices.

3.1.3.1 Energy Sector Emissions

The energy sector included emissions from district heat production plants and power plants, and its contributions to the national emissions by pollutant were as follows: NO_x (11.0%), SO_x (21.9%), PM_{2.5} (3.2%), VOCs (0.8%), and NH₃ (0.5%). To be more specific, emissions of NO_x, SO_x, and PM_{2.5} decreased by 3.7% (2015: 143,000 tons → 2016: 137,744 tons), 0.1% (2015: 78,838 tons → 2016: 78,779 tons), and 9.9% (2015: 3,584 tons → 2016: 3,230 tons), respectively, compared to the previous year while VOCs and NH₃ emissions increased by 8.0% (2015: 7,137 tons → 2016: 7,706 tons) and 17.0% (2015: 1,181 tons → 2016: 1,382 tons), respectively (Table 4 and Fig. 2). There was an increase in fuel consumption; nevertheless, there was an overall decrease in the emissions in this sector due to tighter standards in environmental management for each power plant resulting from domestic issues regarding particulate matter.

The public power generation category's contributions to the emissions in the energy sector by pollutant were as follows: NO_x (79.7%), SO_x (90.8%), PM_{2.5} (80.3%), VOCs (62.7%), and NH₃ (51.2%). Specifically, emissions of NO_x, SO_x, and PM_{2.5} decreased by 5.6% (2015: 116,250 tons → 2016: 109,721 tons), 0.03% (2015: 71,515 tons → 2016: 71,497 tons), and 13.3% (2015: 2,989 tons → 2016: 2,593 tons), respectively, compared to the previous year while VOCs and NH₃ emissions increased by 7.5% (2015: 4,497 tons → 2016: 4,832 tons) and 27.0% (2015: 557 tons → 2016: 708 tons), respectively. While there were increases in fuel consumption such as bituminous coal and LNG compared to the previous year, the emissions by pollutant decreased

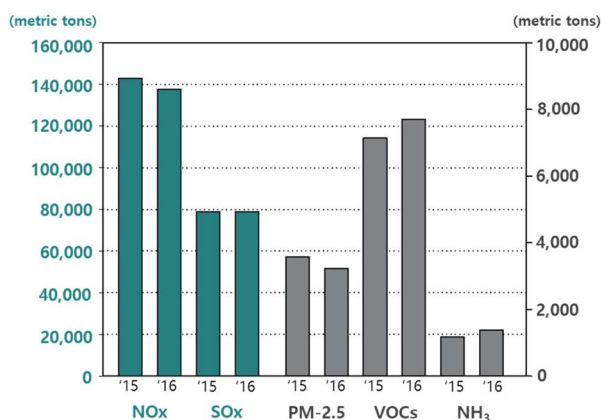


Fig. 2. Emissions in the energy sector by pollutant in 2015 and 2016.

because tighter standards in environmental management forced each power plant to use reduction catalysts and to improve desulfurization facilities for NO_x and SO_x reduction and dust collectors such as electric precipitators (ESP) to remove PM_{2.5}.

The contributions of the private power generation category to the emissions in the energy sector by pollutant were as follows: NO_x (17.4%), SO_x (7.4%), PM_{2.5} (16.0%), VOCs (29.6%), and NH₃ (37.3%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 5.8% (2015: 22,634 tons → 2016: 23,948 tons), 1.1% (2015: 5,791 tons → 2016: 5,856 tons), 4.3% (2015: 496 tons → 2016: 517 tons), 5.2% (2015: 2,169 tons → 2016: 2,282 tons), and 4.2% (2015: 496 tons → 2016: 516 tons), respectively, compared to the previous year. This was the result of increases in consumption of bituminous coal (13.1%, 2015: 5,718 tons → 2016: 6,466 tons) and LNG (4.7%, 2015: 9.429 billion m³ → 2016: 9.876 billion m³) compared to the previous year.

Table 5. Changes in emissions and percentage in the industry sector by pollutant.

(units: tons/year)

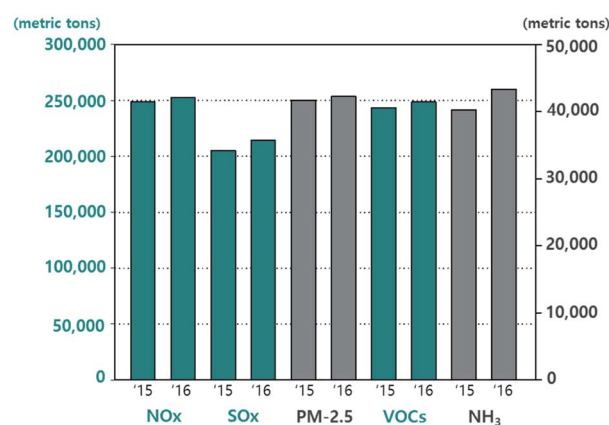
Source sector	Pollutant	Emissions		Change (Emissions)	Change (Percentage)
		2015	2016		
Industry	NO _x	248,765	252,534	3,770	1.5%
	SO _x	205,007	214,406	9,399	4.6%
	PM _{2.5}	41,682	42,251	569	1.4%
	VOCs	243,401	248,730	5,329	2.2%
	NH ₃	40,279	43,360	3,081	7.6%

3. 1. 3. 2 Industry Sector Emissions

Emissions in the industry sector were estimated by summing up those in the categories of manufacturing industry, industrial processes, waste, and oil refineries. Overall, this sector's contributions to the national emissions by pollutant were as follows: NO_x (20.2%), SO_x (59.7%), PM_{2.5} (42.1%), VOCs (24.3%), and NH₃ (14.4%); emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 1.5% (2015: 248,765 tons → 2016: 252,534 tons), 4.6% (2015: 205,007 tons → 2016: 214,406 tons), 1.4% (2015: 41,682 tons → 2016: 42,251 tons), 2.2% (2015: 243,401 tons → 2016: 248,730 tons), and 7.6% (2015: 40,279 tons → 2016: 43,360 tons), respectively, compared to the previous year (Table 5 and Fig. 3).

The contributions of the manufacturing industry category to the emissions in the industry sector by pollutant were as follows: NO_x (69.4%), SO_x (40.4%), PM_{2.5} (87.1%), VOCs (1.3%), and NH₃ (1.5%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 3.7% (2015: 169,139 tons → 2016: 175,332 tons), 1.8% (2015: 85,098 tons → 2016: 86,593 tons), 1.3% (2015: 36,317 tons → 2016: 36,785 tons), 7.8% (2015: 3,101 tons → 2016: 3,342 tons), and 7.1% (2015: 627 tons → 2016: 672 tons), respectively, compared to the previous year. These increases resulted from higher consumption of anthracite coal (6.5%, 2015: 8.383 million tons → 2016: 8.927 million tons) and propane (76.4%, 2015: 3.534 billion m³ → 2016: 6.235 billion m³) by the manufacturing industry compared to the previous years.

The contributions of the industrial processes category to the emissions in the industry sector by pollutant were as follows: NO_x (22.1%), SO_x (52.6%), PM_{2.5} (12.3%), VOCs (74.8%), and NH₃ (98.0%). Compared to the previous year, emissions of NO_x saw a decrease of 6.5% (2015: 59,830 tons → 2016: 55,932 tons) while SO_x,

**Fig. 3.** Emissions in the industry sector by pollutant in 2015 and 2016.

PM_{2.5}, VOCs, and NH₃ emissions increased by 7.0% (2015: 105,385 tons → 2016: 112,734 tons), 1.2% (2015: 5,132 tons → 2016: 5,191 tons), 1.8% (2015: 182,899 tons → 2016: 186,104 tons), and NH₃ 7.8% (2015: 39,432 tons → 2016: 42,489 tons), respectively. This was because of a 4.8% increase (2015: 150.862 million kL → 2016: 158.039 million kL) in consumption of crude oil by the petroleum product manufacturing industry in addition to the decreased output of crude steel (0.5%, 2015: 21.170 million tons → 2016: 21.054 million tons) and of sintered products (2.6%, 2015: 61.926 million tons → 2016: 60.328 million tons), respectively, in the iron and steel industry.

The contributions of the waste category to the emissions in the industry sector by pollutant were as follows: NO_x (5.4%), SO_x (1.0%), PM_{2.5} (0.6%), VOCs (23.7%), and NH₃ (0.1%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 13.3% (2015: 11,977 tons → 2016: 13,570 tons), 2.0% (2015: 2,119 tons → 2016: 2,161 tons), 20.3% (2015: 209 tons → 2016: 252 tons),

Table 6. Changes in emissions and percentage in the road sector by pollutant. (units: tons/year)

Source sector	Pollutant	Emissions		Change (Emissions)	Change (Percentage)
		2015	2016		
Road	NO _x	369,585	452,995	83,410	22.6%
	SO _x	209	231	23	10.9%
	PM _{2.5}	8,817	9,748	932	10.6%
	VOCs	46,145	47,561	1,416	3.1%
	NH ₃	10,078	5,071	-5,008	-49.7%

3.4% (2015: 57,074 tons → 2016: 58,988 tons), and 0.8% (2015: 21.9 tons → 2016: 22.1 tons), respectively, compared to the previous year. This was due to the increased amount of incinerated municipal solid waste (7.3%, 2015: 5.019 million tons → 2016: 5.388 million tons) and industrial waste (7.5%, 2015: 7.172 million tons → 2016: 7.710 million tons) compared to the previous year.

3. 1. 3. 3 Road Sector Emissions

The road sector included emissions from passenger cars and freight cars, and its contributions to the national emissions by pollutant were as follows: NO_x (36.3%), SO_x (0.1%), PM_{2.5} (9.7%), VOCs (4.6%), and NH₃ (1.7%). Emissions of NO_x, SO_x, PM_{2.5}, and VOCs increased by 22.6% (2015: 369,585 tons → 2016: 452,995 tons), 10.9% (2015: 209 tons → 2016: 231 tons), 10.6% (2015: 8,817 tons → 2016: 9,748 tons), and 3.1% (2015: 46,145 tons → 2016: 47,561 tons), respectively, compared to the previous year while NH₃ emissions decreased by 49.7% (2015: 10,078 tons → 2016: 5,071 tons) (Table 6 and Fig. 4).

These changes in the emissions were made because of fluctuations in the number of recent cars registered and vehicle kilometers traveled (VKT) by vehicle type (Table 7). Incidentally, improvements in emissions factors for PM_{2.5} and NH₃ led to marked changes in emissions of the pollutants from each vehicle type.

The contributions of the passenger cars category to the emissions in the road sector by pollutant were as follows: NO_x (9.1%), SO_x (35.4%), PM_{2.5} (1.5%), VOCs (33.4%), and NH₃ (89.8%). Emissions of NO_x, SO_x, and PM_{2.5} increased by 13.8% (2015: 36,193 tons → 2016: 41,190 tons), 21.8% (2015: 67 tons → 2016: 82 tons), 80.3% (2015: 81 tons → 2016: 145 tons), respectively, compared to the previous year while VOCs and NH₃

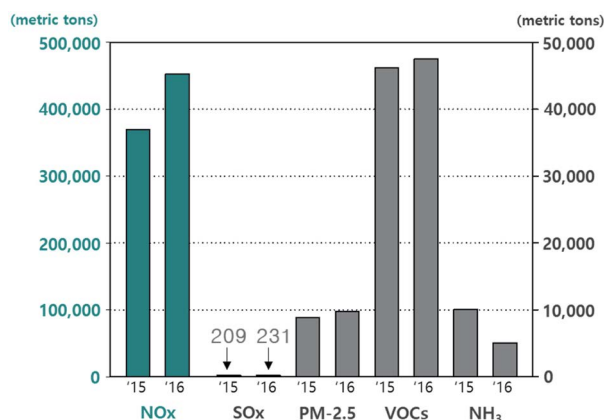


Fig. 4. Emissions in the road sector by pollutant in 2015 and 2016.

emissions decreased by 1.2% (2015: 16,071 tons → 2016: 15,877 tons) and 53.8% (2015: 9,863 tons → 2016: 4,554 tons), respectively. This was because the number of passenger cars registered increased by 2.8% (2015: 12.145 million units → 2016: 12.495 million units) and so did the VKT of the vehicles by 7.2% (2015: 142.662 billion km → 2016: 153.686 billion km) compared to the previous year, contributing to the emissions increases.

The contributions of the large freight cars category to the emissions in the road sector by pollutant were as follows: NO_x (21.9%), SO_x (12.5%), PM_{2.5} (33.4%), VOCs (10.1%), and NH₃ (1.3%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 9.8% (2015: 90,323 tons → 2016: 99,203 tons), 16.7% (2015: 25 tons → 2016: 29 tons), 15.5% (2015: 2,822 tons → 2016: 3,260 tons), 18.4% (2015: 4,069 tons → 2016: 4,818 tons), and 126% (2015: 29 tons → 2016: 66 tons), respectively, compared to the previous year. This was due to the fact that the number of large freight cars regis-

Table 7. Changes in the number of registered cars and VKT by vehicle type.

Type of vehicles	Number of cars registered (1,000 units)			VKT (million km)		
	2015	2016	Change	2015	2016	Change
Passenger cars	12,145	12,495	2.8%	142,662	153,686	7.2%
Taxis	248	247	-0.5%	13,725	10,805	-27.0%
Vans	594	765	22.3%	6,626	7,992	17.1%
Buses	74	76	3.2%	7,436	7,538	1.4%
Freight cars	3,434	3,192	-7.6%	64,989	63,578	-2.2%
Special cars	26	24	-9.6%	728	640	-13.8%
RVs	4,547	5,088	10.6%	62,720	72,848	13.9%
Total	21,069	21,888	3.7%	298,887	317,086	5.7%

Table 8. Changes in emissions and percentage in the non-road sector by pollutant.

(units: tons/year)

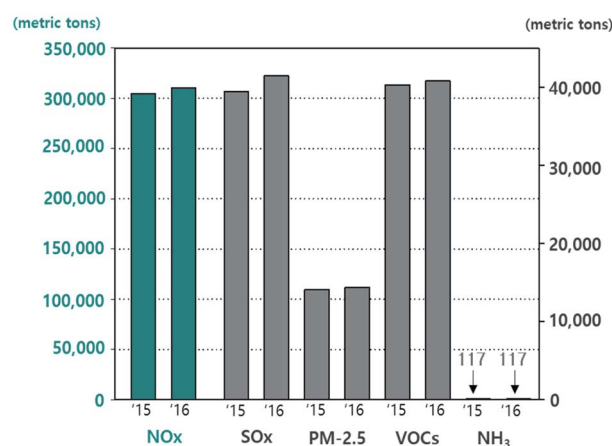
Source sector	Pollutant	Emissions		Change (Emissions)	Change (Percentage)
		2015	2016		
Non-road	NO _x	304,376	309,986	5,611	1.8%
	SO _x	39,424	41,443	2,019	5.1%
	PM _{2.5}	14,106	14,354	248	1.8%
	VOCs	40,311	40,816	505	1.3%
	NH ₃	117	117	1	0.7%

tered increased by 15.3% (2015: 113,000 units → 2016: 131,000 units) with an increase of 14.6% in the VKT of them (2015: 9.8 billion km → 2016: 11.234 billion km) compared to the previous year.

The contributions of RVs category to the emissions in the road sector by pollutant were as follows: NO_x (25.8%), SO_x (13.5%), PM_{2.5} (21.8%), VOCs (6.3%), and NH₃ (3.0%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 59.1% (2015: 73,506 tons → 2016: 116,938 tons), 16.8% (2015: 27 tons → 2016: 31 tons), 5.7% (2015: 2,008 tons → 2016: 2,123 tons), 26.5% (2015: 2,384 tons → 2016: 3,017 tons), and 177% (2015: 56 tons → 2016: 154 tons), respectively, compared to the previous year. This was due to the fact that the number of RVs registered increased by 10.6% (2015: 4.547 million units → 2016: 5.088 million units) with an increase of 15.7% in the VKT of them (2015: 62.720 billion km → 2016: 72.848 billion km), leading to the increases in the emissions.

3.1.3.4 Non-Road Sector Emissions

The non-road sector consisted of categories including

**Fig. 5.** Emissions in the non-road sector by pollutant in 2015 and 2016.

the ships and the construction machineries, and its contributions to the national emissions by pollutant were as follows: NO_x (24.8%), SO_x (11.5%), PM_{2.5} (14.3%), VOCs (4.0%), and NH₃ (0.04%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 1.8%

Table 9. Changes in the number of registered construction machines and working hours by machine type.

Machine type	Number of machines registered			Working hours (1,000 hr/yr)		
	2015	2016	Change	2015	2016	Change
Bulldozers	3,880	3,769	-2.9%	3,756	3,917	4.3%
Loaders	21,979	22,979	4.5%	21,750	22,276	2.4%
Forklifts	164,983	172,284	4.4%	175,261	179,537	2.4%
Excavators	136,244	139,562	2.4%	190,129	194,759	2.4%
Cranes	9,758	10,162	4.1%	11,341	11,970	5.5%
Concrete pumps	6,370	6,676	4.8%	7,769	8,675	11.7%
Rollers	6,417	6,437	0.3%	5,749	6,188	7.6%
Air compressors	4,564	4,496	-1.1%	4,505	4,615	2.4%
Drilling rigs	5,013	5,133	2.4%	3,687	3,777	2.4%

(2015: 304,376 tons → 2016: 309,986 tons), 5.1% (2015: 39,424 tons → 2016: 41,443 tons), 1.8% (2015: 14,106 tons → 2016: 14,354 tons), 1.3% (2015: 40,311 tons → 2016: 40,816 tons), and 0.7% (2015: 116.5 tons → 2016: 117.3 tons), respectively, compared to the previous year; the ships category including cargo ships and fishing vessels and that of construction machineries including forklifts and excavators were major contributors to the emissions (Table 8 and Fig. 5).

Incidentally, the number of forklifts and excavators registered increased by 4.4% and 2.4%, respectively and working hours of the two increased by 2.4% each; conversely, the number of old machineries registered, relatively large emitters, to which the US Tier 1 emissions standards applied, decreased while that of advanced machineries to which the Tier 4 emissions standards could apply increased, resulting in the changes in the emissions (Table 9).

The contributions of the forklifts category to the emissions in the construction machineries category by pollutant were as follows: NO_x (37.2%), SO_x (34.3%), PM_{2.5} (40.3%), VOCs (39.5%), and NH₃ (33.8%). Emissions of NO_x, PM_{2.5}, and VOCs decreased by 3.2% (2015: 44,954 tons → 2016: 43,496 tons), 1.8% (2015: 2,330 tons → 2016: 2,289 tons), and 2.9% (2015: 6,092 tons → 2016: 5,915 tons), respectively, compared to the previous year while NH₃ emissions decreased by 2.3% (2015: 12.9 tons → 2016: 13.2 tons).

The contributions of the excavators category to the emissions in the construction machineries category by pollutant were as follows: NO_x (35.2%), SO_x (40.9%), PM_{2.5} (36.8%), VOCs (31.4%), and NH₃ (41.1%). Emis-

sions of NO_x, PM_{2.5}, and VOCs decreased by 7.4% (2015: 44,496 tons → 2016: 41,208 tons), 5.9% (2015: 2,223 tons → 2016: 2,092 tons), 8.8% (2015: 5,159 tons → 2016: 4,706 tons), respectively, compared to the previous year; on the other hand, SO_x and NH₃ emissions increased by 4.5% (2015: 22 tons → 2016: 23 tons) and 2.6% (2015: 15.7 tons → 2016: 16.1 tons) each.

The contributions of the cargo ships category to the emissions in the ships category by pollutant were as follows: NO_x (56.6%), SO_x (92.6%), PM_{2.5} (67.2%), VOCs (14.3%), and NH₃ (56.0%). Emissions of NO_x, SO_x, PM_{2.5}, VOCs, and NH₃ all increased by 6.7% (2015: 85,768 tons → 2016: 91,539 tons), 2.0% (2015: 36,699 tons → 2016: 37,432 tons), 5.7% (2015: 4,447 tons → 2016: 4,701 tons), 6.8% (2015: 2,970 tons → 2016: 3,171 tons), and 6.7% (2015: 7.6 tons → 2016: 8.1 tons), respectively, compared to the previous year. This was because of the increased number of the ships in and out of ports and higher fuel usage.

The contributions of the fishing vessels category to the emissions in the ships category by pollutant were as follows: NO_x (37.7%), SO_x (1.2%), PM_{2.5} (24.5%), VOCs (64.6%), and NH₃ (37.9%). Emissions of NO_x, PM_{2.5}, and NH₃ increased by 4.0% (2015: 58,564 tons → 2016: 60,928 tons), 0.9% (2015: 1,698 tons → 2016: 1,713 tons), and 3.4% (2015: 5.3 tons → 2016: 5.5 tons), respectively, compared to the previous year while SO_x and VOCs emissions decreased by 5.3% (2015: 519 tons → 2016: 492 tons) and 3.0% (2015: 14,773 tons → 2016: 14,324 tons) each. This was led by an increase in sales of gasoline coupled with decreases both in sales of diesel and in the sulfur content of fuel.

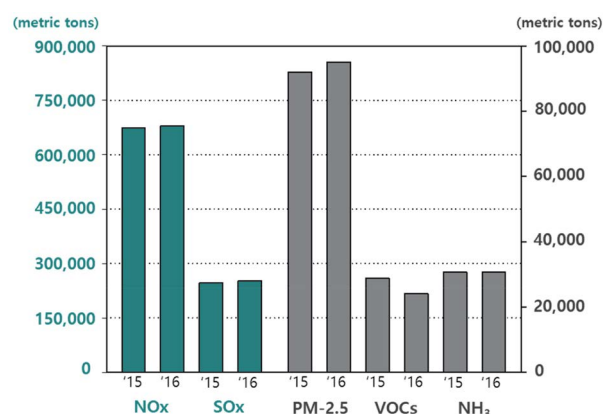
Table 10. Changes in emissions and percentage in the everyday activities and other emission sources sector by pollutant. (units: tons/year)

Source sector	Pollutant	Emissions		Change (Emissions)	Change (Percentage)
		2015	2016		
Everyday activities and other emission sources	NO _x	92,003	95,050	3,047	3.3%
	SO _x	28,815	24,092	-4,722	-16.4%
	PM _{2.5}	30,618	30,664	46	0.1%
	VOCs	673,777	679,216	5,440	0.8%
	NH ₃	245,511	251,371	5,860	2.4%

3.1.3.5 Everyday Activities and Other Emission Sources Sector Emissions

Excluding emission sources from the other sectors (Energy, Industry, Road and Non-road) aforementioned, the everyday activities and other emission sources sector consisted of the categories of non-industry, energy transport and storage, solvent use, agriculture, other (area sources), fugitive dust, and biomass burning. Its contributions to the national emissions by pollutant were as follows: NO_x (7.6%), SO_x (6.7%), PM_{2.5} (30.6%), VOCs (66.3%), and NH₃ (83.4%). Emissions of NO_x, PM_{2.5}, VOCs, and NH₃ increased by 3.3% (2015: 92,003 tons → 2016: 95,050 tons), 0.1% (2015: 30,618 tons → 2016: 30,664 tons), 0.8% (2015: 673,777 tons → 2016: 679,216 tons), and 2.4% (2015: 245,511 tons → 2016: 251,371 tons), respectively, compared to the previous year while SO_x emissions decreased by 16.4% (2015: 28,815 tons → 2016: 24,092 tons) (Table 10 and Fig. 6).

The non-industry category included the categories of commercial, institutional, residential, agricultural and livestock facilities whose emissions were from fuel combustion for heating and other purposes. The non-industry category's contributions to the everyday activities and other emission sources sector by pollutant were as follows: NO_x (90.3%), SO_x (99.7%), PM_{2.5} (3.2%), VOCs (0.4%), and NH₃ (0.6%). Emissions of NO_x, VOCs, and NH₃ increased by 3.5% (2015: 82,948 tons → 2016: 85,824 tons), 4.5% (2015: 2,622 tons → 2016: 2,740 tons), and 4.7% (2015: 1,351 tons → 2016: 1,415 tons), respectively, compared to the previous year while SO_x and PM_{2.5} emissions decreased by 16.4% (2015: 28,736 tons → 2016: 24,015 tons) and 4.6% (2015: 1,025 tons → 2016: 978 tons). Increased NO_x emissions were caused by a 6.9% increase (2015: 9.538 billion m³ → 2016: 10.195 billion m³) in higher LNG consump-

**Fig. 6.** Emissions in the everyday activities and other emission sources sector by pollutant in 2015 and 2016.

tion by commercial, institutional and residential facilities; SO_x emissions were reduced since usage of high sulfur fuel oil (HSFO, 4% B-C oil) decreased by 35.5% (2015: 213,000 kL → 2016: 137,000 kL) compared to the previous year.

The solvent use category (other solvent use, painting facilities, etc.) accounted for 82.2% of VOCs emissions in the everyday activities and other emission sources sector with a 0.5% increase (2015: 555,359 tons → 2016: 558,004 tons), which was found to be due to a 1.2% increase of supply of paints (2015: 808,000 kL → 2016: 818,057 kL) compared to the previous year.

Agriculture (fertilizer use, livestock excrement management, etc.) accounted for 94.3% of NH₃ emissions in the everyday activities and other emission sources sector and saw a 2.5% increase (2015: 231,263 tons → 2016: 237,017 tons) from a year earlier; this was found to be a result of an increase of 2.6% in the number of livestock such as cattle and pigs (2015: 189.417 million animals → 2016: 194.318 million animals) compared

to the previous year.

The fugitive dust category included paved road dust, or resuspended dust from vehicles running on the roads, and dust emitted into the air from industrial processes, not from certain exhaust systems in industries. Fugitive dust accounted for 56.4% of $PM_{2.5}$ emissions in the everyday activities and other emission sources sector, increasing by 0.2% (2015: 17,248 tons → 2016: 17,286 tons) compared to the previous year. Paved road dust, which accounted for 41% of fugitive dust emissions, saw a 6.2% increase in $PM_{2.5}$ emissions (2015: 6,671 tons → 2016: 7,087 tons) compared to the previous year. This was because of increases both in the number of cars registered and in the VKT in the road transport including passenger cars with the number of rain days with 0.254 mm or more (US EPA) decreasing by 3.6% (2015: 130 days → 2016: 125 days) compared to the previous year.

The biomass burning category included the category of burning in everyday life such as open burning of municipal solid waste, and its contributions to emissions in the everyday activities and other emission sources sector by pollutant were as follows: NO_x (9.5%), $PM_{2.5}$ (39.5%), and VOCs (12.9%). Emissions of NO_x , $PM_{2.5}$, and VOCs increased by 2.0% (2015: 8,883 tons → 2016: 9,059 tons), 0.5% (2015: 12,060 tons → 2016: 12,124 tons), and 1.9% (2015: 86,012 tons → 2016: 87,687 tons), respectively, compared to the previous year. This was because the cultivation area for industrial crops (sesame, perilla, groundnut, etc.) expanded by 8.3% (2015: 72,298 ha → 2016: 78,276 ha) compared to the previous year, and the amount of incineration consequently increased.

4. CONCLUSION

Emissions in the Republic of Korea in 2016 were estimated by using the Clean Air Policy Support System (CAPSS), and the total emissions by pollutant were as follows: CO (795,044 tons), NO_x (1,248,309 tons), SO_x (358,951 tons), TSP (611,539 tons), PM_{10} (233,085 tons), $PM_{2.5}$ (100,247 tons), BC (16,401 tons), VOCs 1,024,029 (tons), and NH_3 (301,301). Overall, most pollutants showed increased emissions in 2016 compared to 2015, except for PM_{10} . The percentage increases were 0.3% (CO), 7.8% (NO_x), 1.9% (SO_x), 1.2% (TSP), 1.5% ($PM_{2.5}$), 2.9% (BC), 1.3% (VOCs), and 1.4% (NH_3) with a 0.04% decrease in PM_{10} emissions; the national

emissions in 2016 by sector were as estimated below.

Emissions in the energy sector (public/private power generation, district production plants, etc.), whose main pollutants were NO_x , SO_x , VOCs, and NH_3 contributing to primary and secondary $PM_{2.5}$ formation, were 137,744 tons for NO_x , 78,779 tons for SO_x , 3,230 tons for $PM_{2.5}$, 7,706 tons VOCs, 1,382 tons for NH_3 , accounting for 11.0%, 21.9%, 3.2%, 0.8%, and 0.5% of the national emissions, respectively. Emissions in the industry sector (manufacturing industry, industrial processes, waste, etc.) were 252,534 tons for NO_x , 214,406 tons for SO_x , 42,251 tons for $PM_{2.5}$, 248,730 tons for VOCs, and 43,360 tons for NH_3 , accounting for 20.2%, 59.7%, 42.1%, 24.3%, and 14.4% of the national emissions, respectively. Emissions in the road sector (passenger cars, freight cars, etc.) were 452,995 tons for NO_x , 231 tons for SO_x , 9,748 tons for $PM_{2.5}$, 47,561 tons for VOCs, and 5,071 tons for NH_3 , accounting for 36.3%, 0.1%, 9.7%, 4.6%, and 1.7% of the national emissions, respectively. Emissions in the non-road sector (ships, construction machineries, etc.) were 309,986 tons for NO_x , 41,443 tons for SO_x , 14,354 tons for $PM_{2.5}$, 40,816 tons VOCs, and 117 tons for NH_3 , accounting for 24.8%, 11.5%, 14.3%, 4.0%, and 0.04% of the national emissions, respectively. Emissions in the everyday activities and other emission source sector (non-industry, biomass burning, etc.) were 95,050 tons for NO_x , 24,092 tons for SO_x , 30,664 tons for $PM_{2.5}$, 679,216 tons for VOCs, and 251,371 tons for NH_3 , accounting for 7.6%, 6.7%, 30.6%, 66.3%, and 83.4% of the national emissions, respectively.

The NAIR is conducting various studies in order to improve the reliability of national air pollutant emissions data by identifying exact air pollutant emission sources and resolving the uncertainty of emission statistics. For example, the NAIR is currently carrying out research to improve the existing emission methodologies for estimating emissions from enhancing allocation methods for emissions from area emission sources such as industrial sites, developing measurement-based emission factors to updating antiquated emission factors. Other studies are also being conducted to identify possible missing emissions sources such as ground support equipment (GSE) at airports, cargo handling equipment (CHE) at ports, and the defense sector.

Also, the NAIR is developing a system to evaluate emissions data from wider perspectives. This is because there are limited ways to assess the reliability of emis-

sions data other than those directly measured by the Tele-Monitoring System (TMS) on the smokestack. More recently, in a bid to increase the reliability of emissions data, we are introducing the Community Multi-scale Air Quality Modeling (CMAQ) system, a 3-dimensional chemistry transport model, in which emissions data are entered to simulate the concentrations of pollutants, which are then to be compared with those measured from the surface and satellites.

The data we calculate are used as official national emissions data for the establishment, implementation, and assessment of national atmospheric environment policy to improve air quality. As critical and necessary materials, the data are also utilized on a wide range of studies on policies such as customized regional particulate matter reduction measures. Thus, it is crucial to estimate highly reliable national emissions by enhancing the emissions factors and inventory and to establish a scientific emissions testing system by using air quality modeling and satellite data.

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SUPPLEMENTARY MATERIALS

1. Trends in CO emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	45,376	47,807	41,534	33,425	35,515	6.3%
	District heating production plants	2,976	3,168	3,675	3,365	4,242	26.1%
	Oil refinery	1,121	1,842	2,320	2,136	1,605	-24.9%
	Private power generation	9,717	10,641	10,327	16,212	17,217	6.2%
	Subtotal	59,190	63,457	57,856	55,138	58,579	6.2%
Non industry	Commercial and institutional facilities	11,177	16,989	16,227	16,956	18,896	11.4%
	Residential facilities	66,647	69,180	59,341	54,445	47,997	-11.8%
	Plants in agriculture, forestry and aquaculture	1,328	1,363	1,026	898	842	-6.2%
	Subtotal	79,152	87,532	76,594	72,299	67,735	-6.3%
Manufacturing industry	Combustion facilities	1,222	2,016	1,389	1,608	3,265	103.0%
	Processes	6,261	8,082	6,587	6,607	7,138	8.0%
	Others	11,659	10,028	10,740	8,639	7,767	-10.1%
	Subtotal	19,141	20,125	18,716	16,854	18,170	7.8%
Industrial process	Petroleum industry	12,047	11,322	11,545	12,069	12,643	4.8%
	Iron and steel industry	5,076	5,103	5,638	5,761	5,760	0.0%
	Inorganic chemical industry	477	474	485	487	510	4.7%
	Organic chemical industry	1,263	5,248	5,316	5,011	5,661	13.0%
	Pulp and paper industry	1,545	2,521	2,604	2,469	2,495	1.0%
	Others	240	244	267	272	271	-0.3%
	Subtotal	20,648	24,912	25,855	26,069	27,340	4.9%
Road transport	Passenger cars	137,305	123,022	136,451	123,534	118,777	-3.9%
	Taxis	27,209	27,101	1,757	1,151	740	-35.7%
	Vans	5,319	5,082	3,730	3,203	4,430	38.3%
	Buses	18,441	18,494	9,451	6,805	6,964	2.3%
	Freight cars	65,935	64,108	49,976	48,379	49,643	2.6%
	Special cars	1,160	1,208	1,035	830	1,057	27.4%
	RV	35,312	31,932	26,634	21,349	22,342	4.7%
	Two-wheeled vehicles	151,992	138,271	52,190	40,265	40,604	0.8%
	Subtotal	442,672	409,218	281,225	245,516	244,556	-0.4%
Non-road transport	Railroads	4,039	3,657	3,057	2,734	2,426	-11.3%
	Ships	7,626	7,646	54,535	60,491	62,632	3.5%
	Aircrafts	6,185	7,228	7,117	7,838	8,865	13.1%
	Agricultural machineries	7,287	7,244	7,165	7,097	7,076	-0.3%
	Construction machineries	47,813	56,841	54,229	57,540	55,614	-3.3%
	Subtotal	72,950	82,615	126,103	135,700	136,612	0.7%
Waste	Waste incineration	3,300	1,957	1,645	1,548	2,008	29.8%
Others	Forest fire and other fire	6,533	6,865	6,459	7,197	6,977	-3.1%
Biomass burning	Open burning	8,758	8,565	4,498	4,200	4,080	-2.8%
	Agricultural residue incineration	133,682	132,679	155,437	157,616	159,196	1.0%
	Grilled meat and fish	8	8	12	13	9	-27.6%
	Wood stoves and boilers	94,745	94,745	58,938	57,772	57,029	-1.3%
	Furnace	10,894	10,894	6,031	5,856	5,750	-1.8%
	Charcoal burner	12,816	8,315	7,000	7,000	7,000	0.0%
	Subtotal	260,903	255,206	231,917	232,455	233,066	0.3%
Total		964,490	951,888	826,370	792,776	795,044	0.4%

2. Trends in NO_x emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	132,405	140,096	127,456	116,250	109,721	-5.6%
	District heating production plants	4,032	4,162	4,651	4,116	4,075	-1.0%
	Oil refinery	10,647	9,176	8,066	7,818	7,701	-1.5%
	Private power generation	22,261	23,784	22,644	22,634	23,948	5.8%
	Subtotal	169,346	177,219	162,818	150,818	145,445	-3.6%
Non industry	Commercial and institutional facilities	30,141	31,303	29,871	32,630	34,249	5.0%
	Residential facilities	52,325	51,882	47,055	46,605	48,101	3.2%
	Plants in agriculture, forestry and aquaculture	5,469	5,584	4,216	3,712	3,474	-6.4%
	Subtotal	87,935	88,769	81,143	82,948	85,824	3.5%
Manufacturing industry	Combustion facilities	10,767	13,706	13,612	13,955	17,137	22.8%
	Processes	85,180	94,292	95,197	94,326	98,494	4.4%
	Others	76,813	70,036	64,852	60,858	59,702	-1.9%
	Subtotal	172,761	178,034	173,660	169,139	175,332	3.7%
Industrial process	Petroleum industry	1,764	4,632	4,478	4,799	4,932	2.8%
	Iron and steel industry	47,339	38,622	38,485	43,671	43,352	-0.7%
	Inorganic chemical industry	3,881	5,408	4,284	4,882	2,752	-43.6%
	Organic chemical industry	28	32	23	16	19	20.0%
	Others	5,990	6,457	6,042	6,462	4,877	-24.5%
Subtotal	59,002	55,151	53,311	59,830	55,932	-6.5%	
Road transport	Passenger cars	23,796	21,697	34,036	36,193	41,190	13.8%
	Taxis	6,607	6,722	487	363	249	-31.3%
	Vans	10,741	11,187	15,346	13,121	17,350	32.2%
	Buses	36,062	35,774	31,365	34,097	32,011	-6.1%
	Freight cars	232,970	224,980	204,086	206,915	239,450	15.7%
	Special cars	2,772	2,550	2,482	2,479	2,833	14.3%
	RV	29,345	29,353	70,509	73,506	116,938	59.1%
	Two-wheeled vehicles	3,373	3,458	2,919	2,911	2,974	2.2%
Subtotal	345,666	335,721	361,230	369,585	452,995	22.6%	
Non-road transport	Railroads	9,897	8,943	7,476	6,688	5,932	-11.3%
	Ships	89,658	89,887	144,030	151,735	161,826	6.7%
	Aircrafts	6,368	7,423	7,323	8,058	9,104	13.0%
	Agricultural machineries	16,470	16,447	16,288	16,209	16,190	-0.1%
	Construction machineries	103,169	123,327	116,053	121,686	116,934	-3.9%
	Subtotal	225,561	246,027	291,171	304,376	309,986	1.8%
Waste	Waste incineration	14,782	9,529	12,257	11,977	13,570	13.3%
Others	Forest fire and other fire	154	165	153	172	167	-3.2%
Biomass burning	Open burning	623	609	590	550	535	-2.8%
	Agricultural residue incineration	4,983	4,954	5,423	5,606	5,816	3.7%
	Grilled meat and fish	6	6	9	9	7	-27.2%
	Wood stoves and boilers	2,540	2,540	2,205	2,195	2,188	-0.3%
	Furnace	954	954	528	513	504	-1.8%
	Charcoal burner	70	46	10	10	10	0.0%
Subtotal	9,177	9,110	8,765	8,883	9,059	2.0%	
Total		1,084,383	1,099,723	1,144,508	1,157,728	1,248,309	7.8%

3. Trends in SO_x emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	73,801	78,786	73,506	71,515	71,497	-0.03%
	District heating production plants	797	1,337	1,920	1,531	1,425	-6.9%
	Oil refinery	8,090	6,749	13,071	12,405	12,917	4.1%
	Private power generation	8,365	10,692	6,065	5,791	5,856	1.1%
	Subtotal	91,053	97,565	94,562	91,243	91,696	0.5%
Non industry	Commercial and institutional facilities	19,339	9,296	6,328	12,015	9,744	-18.9%
	Residential facilities	19,496	20,253	17,111	15,471	13,204	-14.7%
	Plants in agriculture, forestry and aquaculture	1,411	1,551	1,229	1,249	1,067	-14.6%
	Subtotal	40,245	31,101	24,668	28,736	24,015	-16.4%
Manufacturing industry	Combustion facilities	4,229	3,655	3,232	2,441	2,727	11.7%
	Processes	17,550	19,954	19,456	18,811	18,505	-1.6%
	Others	74,837	72,227	60,294	63,847	65,362	2.4%
	Subtotal	96,617	95,836	82,982	85,098	86,593	1.8%
Industrial process	Petroleum industry	55,226	59,858	57,572	57,789	61,756	6.9%
	Iron and steel industry	48,574	36,723	29,600	35,538	39,451	11.0%
	Inorganic chemical industry	2,031	1,533	1,915	1,706	1,178	-30.9%
	Organic chemical industry	583	360	375	448	463	3.3%
	Pulp and paper industry	76	125	129	122	123	1.0%
	Others	10,702	9,735	9,337	9,781	9,762	-0.2%
	Subtotal	117,191	108,333	98,927	105,385	112,734	7.0%
Road transport	Passenger cars	63	55	63	67	82	21.8%
	Taxis	12	6	5	7	4	-45.7%
	Vans	5	4	5	5	5	10.9%
	Buses	9	9	9	11	12	9.2%
	Freight cars	84	82	69	82	85	4.1%
	Special cars	2	1	2	2	2	-10.4%
	RV	27	24	23	27	31	16.8%
	Two-wheeled vehicles	8	8	8	8	10	25.5%
	Subtotal	211	189	183	209	231	10.9%
Non-road transport	Railroads	255	228	191	171	151	-11.3%
	Ships	64,295	64,186	39,074	38,467	40,429	5.1%
	Aircrafts	595	650	678	729	802	10.1%
	Agricultural machineries	4	4	4	4	4	2.0%
	Construction machineries	39	51	45	53	56	5.5%
	Subtotal	65,188	65,119	39,991	39,424	41,443	5.1%
Waste	Waste incineration	7,140	6,517	1,846	2,119	2,161	2.0%
Biomass burning	Grilled meat and fish	1	1	2	2	1	-27.8%
	Wood stoves and boilers	121	121	62	60	60	-1.1%
	Furnace	17	17	9	9	9	-1.8%
	Charcoal burner	14	9	8	8	8	0.0%
	Subtotal	153	148	80	79	78	-1.7%
Total		417,798	404,808	343,241	352,292	358,951	4.6%

4. Trends in TSP emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	4,108	4,181	3,976	3,812	3,337	-12.5%
	District heating production plants	76	114	108	132	149	12.3%
	Oil refinery	184	140	169	182	157	-13.8%
	Private power generation	525	527	481	565	630	11.5%
	Subtotal	4,893	4,961	4,733	4,692	4,273	-8.9%
Non industry	Commercial and institutional facilities	237	145	121	184	165	-10.4%
	Residential facilities	1,720	1,703	1,447	1,349	1,238	-8.2%
	Plants in agriculture, forestry and aquaculture	442	440	340	308	291	-5.5%
	Subtotal	2,398	2,289	1,908	1,841	1,694	-8.0%
Manufacturing industry	Combustion facilities	251	220	449	445	408	-8.3%
	Processes	3,387	4,763	3,771	3,825	3,196	-16.4%
	Others	129,672	133,843	98,518	117,399	119,533	1.8%
	Subtotal	133,310	138,826	102,738	121,668	123,138	1.2%
Industrial process	Petroleum industry	363	447	466	459	502	9.4%
	Iron and steel industry	8,526	7,372	7,617	7,740	7,797	0.7%
	Inorganic chemical industry	870	644	635	620	634	2.2%
	Organic chemical industry	2,320	1,497	1,558	1,844	1,911	3.7%
	Pulp and paper industry	47	48	44	44	44	-1.5%
	Others	1,827	1,811	1,847	1,168	1,168	0.0%
	Subtotal	13,954	11,819	12,167	11,876	12,056	1.5%
Road transport	Passenger cars	43	62	81	88	158	80.3%
	Taxi					2	
	Vans	619	599	435	328	437	33.1%
	Buses	346	274	223	234	222	-5.3%
	Freight cars	8,933	8,409	6,839	6,694	7,296	9.0%
	Special cars	106	84	74	58	97	68.2%
	RV	2,924	2,675	2,367	2,182	2,307	5.7%
	Motorcycles					78	
	Subtotal	12,969	12,103	10,019	9,583	10,596	10.6%
Non-road transport	Railroads	646	579	484	433	384	-11.3%
	Ships	6,905	6,922	6,983	7,091	7,589	7.0%
	Aircrafts	81	93	89	94	103	9.9%
	Agricultural machineries	1,390	1,380	1,364	1,348	1,342	-0.4%
	Construction machineries	5,313	6,196	5,945	6,354	6,173	-2.9%
	Subtotal	14,336	15,170	14,865	15,320	15,592	1.8%
Waste	Waste incineration	456	330	335	340	406	19.6%
Others	Forest fire and other fire	428	488	428	498	481	-3.5%
Fugitive dust	Paved road dust	134,261	136,717	140,840	143,644	152,599	6.2%
	Construction	34,216	34,243	40,356	55,714	51,005	-8.5%
	Playground	55,428	32,534	27,519	27,403	24,712	-9.8%
	Load and unload	27	25	25	26	26	-2.8%
	Agricultural	30,583	29,657	29,553	29,072	28,549	-1.8%
	Livestock	28,987	29,263	29,745	30,524	31,898	4.5%
	Waste	13,166	13,112	12,655	14,414	15,498	7.5%
	Unpaved road dust	244,283	273,654	115,250	107,445	108,400	0.9%
	Subtotal	540,950	549,207	395,944	408,242	412,686	1.1%
Biomass burning	Open burning	1,518	1,485	1,438	1,342	1,304	-2.8%
	Agricultural residue incineration	21,334	21,174	22,085	22,126	22,832	3.2%
	Grilled meat and fish	394	420	606	626	461	-26.4%
	Wood stoves and boilers	7,225	7,225	4,173	4,072	4,008	-1.6%
	Furnace	314	314	173	168	165	-1.8%
	Charcoal burner	2,978	1,932	1,849	1,849	1,849	0.0%
Subtotal	33,762	32,550	30,323	30,183	30,618	1.4%	
Total		757,456	767,743	573,460	604,243	611,539	1.2%

5. Trends in PM₁₀ emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	3,920	3,831	3,854	3,681	3,194	-13.2%
	District heating production plants	64	95	85	113	133	18.3%
	Oil refinery	109	89	104	57	53	-7.4%
	Private power generation	489	509	465	544	571	5.0%
	Subtotal	4,582	4,524	4,508	4,394	3,951	-10.1%
Non industry	Commercial and institutional facilities	219	135	112	170	152	-10.7%
	Residential facilities	1,439	1,416	1,206	1,129	1,048	-7.1%
	Plants in agriculture, forestry and aquaculture	405	404	312	283	267	-5.5%
	Subtotal	2,062	1,955	1,629	1,582	1,468	-7.2%
Manufacturing industry	Combustion facilities	208	180	323	249	240	-3.6%
	Processes	2,111	2,900	2,282	2,290	1,955	-14.6%
	Others	75,515	77,933	57,370	68,354	69,599	1.8%
	Subtotal	77,833	81,014	59,975	70,893	71,794	1.3%
Industrial process	Petroleum industry	105	129	135	133	145	9.4%
	Iron and steel industry	5,454	4,645	4,755	4,833	4,856	0.5%
	Inorganic chemical industry	488	367	359	348	356	2.4%
	Organic chemical industry	1,183	764	795	940	975	3.7%
	Pulp and paper industry	28	29	27	27	26	-1.5%
	Others	342	314	337	377	373	-1.2%
	Subtotal	7,600	6,249	6,407	6,658	6,731	1.1%
Road transport	Passenger cars	43	62	81	88	158	80.3%
	Taxi					2	
	Vans	619	599	435	328	437	33.1%
	Buses	346	274	223	234	222	-5.3%
	Freight cars	8,933	8,409	6,839	6,694	7,296	9.0%
	Special cars	106	84	74	58	97	68.2%
	RV	2,924	2,675	2,367	2,182	2,307	5.7%
	Motorcycles					78	
	Subtotal	12,969	12,103	10,019	9,583	10,596	10.6%
Non-road transport	Railroads	646	579	484	433	384	-11.3%
	Ships	6,905	6,922	6,983	7,091	7,589	7.0%
	Aircrafts	78	90	85	90	99	9.9%
	Agricultural machineries	1,390	1,380	1,364	1,348	1,342	-0.4%
	Construction machineries	5,313	6,196	5,945	6,354	6,173	-2.9%
	Subtotal	14,332	15,167	14,861	15,317	15,588	1.8%
Waste	Waste incineration	330	243	247	246	295	19.6%
Others	Forest fire and other fire	272	310	272	317	306	-3.5%
Fugitive dust	Paved road dust	25,772	26,243	27,034	27,573	29,291	6.2%
	Construction	23,472	23,491	27,685	38,221	34,990	-8.5%
	Playground	21,617	12,688	10,733	10,687	9,638	-9.8%
	Load and unload	9	9	9	9	9	-2.8%
	Agricultural	10,439	10,142	10,141	9,961	9,791	-1.7%
	Livestock	9,684	9,778	9,939	10,200	10,658	4.5%
	Waste	3,537	3,525	3,416	3,926	4,220	7.5%
	Unpaved road dust	20,591	23,067	9,715	9,057	9,137	0.9%
	Subtotal	115,121	108,942	98,671	109,633	107,735	-1.7%
	Biomass burning	Open burning	1,038	1,015	984	919	893
Agricultural residue incineration		8,869	8,820	9,121	9,183	9,474	3.2%
Grilled meat and fish		394	420	606	626	461	-26.4%
Wood stoves and boilers		3,365	3,365	2,002	1,958	1,930	-1.4%
Furnace		206	206	114	111	109	-1.8%
Charcoal burner		2,830	1,836	1,757	1,757	1,757	0.0%
Subtotal		16,702	15,663	14,583	14,552	14,623	0.5%
Total		251,804	246,168	211,172	233,177	233,085	-0.04%

6. Trends in PM_{2.5} emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	3,161	3,006	3,162	2,989	2,593	-13.3%
	District heating production plants	53	78	63	99	120	21.2%
	Oil refinery	42	43	46	23	23	-1.4%
	Private power generation	404	446	407	496	517	4.3%
	Subtotal	3,660	3,573	3,679	3,607	3,253	-9.8%
Non industry	Commercial and institutional facilities	134	87	72	109	98	-9.5%
	Residential facilities	889	889	782	745	721	-3.2%
	Plants in agriculture, forestry and aquaculture	246	250	191	171	159	-7.5%
	Subtotal	1,269	1,226	1,045	1,025	978	-4.6%
Manufacturing industry	Combustion facilities	117	101	165	121	148	22.7%
	Processes	1,103	1,525	1,245	1,226	1,059	-13.6%
	Others	38,480	39,980	28,912	34,971	35,577	1.7%
	Subtotal	39,700	41,606	30,322	36,317	36,785	1.3%
Industrial process	Petroleum industry	23	28	30	29	32	9.4%
	Iron and steel industry	4,319	3,603	3,636	3,705	3,730	0.7%
	Inorganic chemical industry	298	209	202	194	199	2.2%
	Organic chemical industry	1,065	687	715	846	877	3.7%
	Pulp and paper industry	19	19	17	18	17	-1.9%
	Others	307	283	303	340	336	-0.9%
	Subtotal	6,032	4,829	4,903	5,132	5,191	1.2%
Road transport	Passenger cars	40	57	75	81	145	80.3%
	Taxi					2	
	Vans	569	551	400	302	402	33.1%
	Buses	318	252	205	215	204	-5.3%
	Freight cars	8,218	7,736	6,292	6,159	6,712	9.0%
	Special cars	97	77	68	53	89	68.2%
	RV	2,690	2,461	2,178	2,008	2,123	5.7%
	Motorcycles					72	
	Subtotal	11,932	11,135	9,218	8,817	9,748	10.6%
Non-road transport	Railroads	594	533	446	399	354	-11.3%
	Ships	6,352	6,369	6,423	6,539	6,995	7.0%
	Aircrafts	72	82	78	83	91	9.9%
	Agricultural machineries	1,279	1,269	1,255	1,240	1,235	-0.4%
	Construction machineries	4,888	5,700	5,469	5,846	5,679	-2.9%
	Subtotal	13,186	13,953	13,671	14,106	14,354	1.8%
Waste	Waste incineration	265	202	204	209	252	20.3%
Others	Forest fire and other fire	244	279	245	285	275	-3.5%
Fugitive dust	Paved road dust	6,235	6,349	6,541	6,671	7,087	6.2%
	Construction	2,347	2,349	2,769	3,822	3,499	-8.5%
	Playground	3,243	1,903	1,610	1,603	1,446	-9.8%
	Load and unload	1	1	1	1	1	-2.8%
	Agricultural	2,088	2,028	2,028	1,992	1,958	-1.7%
	Livestock	1,842	1,837	1,840	1,861	1,960	5.4%
	Waste	354	352	342	393	422	7.5%
	Unpaved road dust	2,059	2,307	971	906	914	0.9%
	Subtotal	18,168	17,127	16,101	17,248	17,286	0.2%
Biomass burning	Open burning	921	901	873	815	792	-2.8%
	Agricultural residue incineration	7,330	7,290	7,563	7,621	7,878	3.4%
	Grilled meat and fish	365	389	556	574	423	-26.2%
	Wood stoves and boilers	2,197	2,197	1,326	1,298	1,280	-1.4%
	Furnace	164	164	92	89	87	-1.8%
	Charcoal burner	2,683	1,740	1,664	1,664	1,664	0.0%
Subtotal	13,659	12,681	12,073	12,060	12,124	0.5%	
Total		108,114	106,610	91,460	98,806	100,247	1.5%

7. Trends in Black Carbon emissions

(units: tons/year)

Emission source category		2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	219	146	151	3.5%
	District heating production plants	17	28	36	28.3%
	Oil refinery	5	1	2	69.6%
	Private power generation	83	132	141	6.6%
	Subtotal	324	307	330	7.3%
Non industry	Commercial and institutional facilities	9	13	13	-0.2%
	Residential facilities	130	128	136	6.1%
	Plants in agriculture, forestry and aquaculture	16	14	13	-6.9%
	Subtotal	156	155	161	4.4%
Manufacturing industry	Combustion facilities	20	14	35	144.1%
	Processes	74	60	62	2.0%
	Others	554	666	679	2.0%
	Subtotal	648	741	776	4.8%
Industrial process	Petroleum industry	0.02	0.02	0	9.4%
	Iron and steel industry	11	11	11	-1.1%
	Pulp and paper industry	0.1	0.1	0	-7.5%
	Others	4	5	6	14.6%
	Subtotal	15	16	17	3.8%
Road transport	Passenger cars	33	39	60	53.5%
	Vans	240	183	237	30.0%
	Buses	158	166	157	-5.3%
	Freight cars	3,939	3,873	4,187	8.1%
	Special cars	52	41	69	68.2%
	RV	1,252	1,154	1,219	5.7%
	Subtotal	5,674	5,456	5,930	8.7%
Non-road transport	Railroads	344	308	273	-11.3%
	Ships	1,004	1,042	1,105	6.0%
	Aircrafts	61	64	70	9.9%
	Agricultural machineries	968	956	953	-0.4%
	Construction machineries	4,218	4,509	4,380	-2.9%
	Subtotal	6,594	6,879	6,781	-1.4%
Waste	Waste incineration	3	3	4	20.3%
Others	Forest fire and other fire	11	15	14	-4.4%
Fugitive dust	Paved road dust	68	70	74	6.2%
	Playground	0.3	0.3	0.3	-9.8%
	Load and unload	0.04	0.04	0.04	-2.8%
	Agricultural	0.4	0.4	0.4	-1.7%
	Livestock	28	27	30	9.0%
	Unpaved road dust	11	10	10	0.9%
	Subtotal	108	108	115	6.3%
Biomass burning	Open burning	37	34	33	-2.8%
	Agricultural residue incineration	1,707	1,709	1,738	1.7%
	Grilled meat and fish	23	23	17	-26.2%
	Wood stoves and boilers	219	213	210	-1.6%
	Furnace	13	13	13	-1.8%
	Charcoal burner	263	263	263	0.0%
	Subtotal	2,261	2,255	2,274	0.8%
Total		15,795	15,934	16,401	2.9%

8. Trends in VOCs emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016–2015)
Energy production	Public power generation	6,032	6,331	5,486	4,497	4,832	7.5%
	District heating production plants	416	432	509	472	591	25.3%
	Oil refinery	262	352	318	327	296	-9.6%
	Private power generation	1,282	1,430	1,384	2,169	2,282	5.2%
	Subtotal	7,992	8,545	7,697	7,464	8,001	7.2%
Non industry	Commercial and institutional facilities	931	774	722	795	810	1.8%
	Residential facilities	1,944	1,932	1,777	1,773	1,879	6.0%
	Plants in agriculture, forestry and aquaculture	79	79	59	53	51	-3.8%
	Subtotal	2,953	2,784	2,558	2,622	2,740	4.5%
Manufacturing industry	Combustion facilities	184	282	193	222	447	101.3%
	Processes	902	1,169	1,134	1,079	1,176	9.0%
	Others	2,287	2,086	1,953	1,800	1,719	-4.5%
	Subtotal	3,373	3,537	3,280	3,101	3,342	7.8%
Industrial process	Petroleum industry	55,919	52,553	53,588	56,021	58,686	4.8%
	Iron and steel industry	17,845	17,847	19,325	19,408	19,546	0.7%
	Inorganic chemical industry	624	606	579	564	613	8.7%
	Organic chemical industry	41,289	43,790	44,050	44,417	45,508	2.5%
	Pulp and paper industry	1	1	1	1	1	0.0%
	Food and beverage industry	50,509	58,871	62,275	61,943	61,206	-1.2%
	Others	479	487	534	544	543	-0.3%
	Subtotal	166,668	174,156	180,351	182,899	186,104	1.8%
Energy transport and storage	Gasoline supply	26,985	27,241	27,645	29,137	30,160	3.5%
Solvents use	Painting facilities	358,870	354,465	339,582	344,671	347,608	0.9%
	Washing facilities	25,462	26,835	27,701	28,144	27,740	-1.4%
	Laundry facilities	22,115	21,836	21,304	20,407	20,390	-0.1%
	Other solvent use	159,048	158,934	160,731	162,137	162,266	0.1%
	Subtotal	565,495	562,070	549,318	555,359	558,004	0.5%
Road transport	Passenger cars	19,138	17,536	18,045	16,071	15,877	-1.2%
	Taxis	1,043	1,017	89	61	38	-36.8%
	Vans	1,130	1,164	632	531	669	25.9%
	Buses	12,474	12,850	12,134	12,366	11,936	-3.5%
	Freight cars	14,828	14,848	11,436	11,514	12,700	10.3%
	Special cars	294	311	266	246	317	28.9%
	RV	2,916	2,824	2,610	2,384	3,017	26.5%
	Two-wheeled vehicles	15,954	15,258	4,255	2,973	3,008	1.2%
Subtotal	67,776	65,807	49,468	46,145	47,561	3.1%	
Non-road transport	Railroads	1,620	1,466	1,225	1,095	973	-11.2%
	Ships	2,473	2,480	18,340	20,970	22,185	5.8%
	Aircrafts	560	578	672	700	749	7.1%
	Agricultural machineries	1,997	1,978	1,955	1,933	1,925	-0.4%
	Construction machineries	13,623	15,785	14,681	15,613	14,984	-4.0%
	Subtotal	20,274	22,288	36,873	40,311	40,816	1.3%
Waste	Waste incineration	44,843	42,907	44,612	53,173	55,520	4.4%
	Others	4,414	3,601	3,449	3,901	3,468	-11.1%
	Subtotal	49,257	46,508	48,061	57,074	58,988	3.4%
Others	Forest fire and other fire	549	637	551	648	624	-3.6%

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Biomass burning	Open burning	5,086	4,974	4,807	4,488	4,361	-2.8%
	Agricultural residue incineration	61,210	60,450	61,154	61,408	63,497	3.4%
	Grilled meat and fish	103	107	147	154	110	-28.7%
	Wood stoves and boilers	28,154	28,154	17,406	17,071	16,858	-1.2%
	Furnace	3,046	3,046	1,687	1,638	1,608	-1.8%
	Charcoal burner	7,331	4,757	1,254	1,254	1,254	0.0%
	Subtotal	104,930	101,487	86,454	86,012	87,687	1.9%
Total		1,016,252	1,015,059	992,256	1,010,771	1,024,029	1.9%

9. Trends in NH₃ emissions

(units: tons/year)

Emission source category		2012	2013	2014	2015	2016	Change (2016-2015)
Energy production	Public power generation	1,008	1,117	798	557	708	27.0%
	District heating production plants	123	122	145	128	158	23.2%
	Oil refinery	163	181	174	198	177	-10.6%
	Private power generation	293	325	308	496	516	4.2%
	Subtotal	1,586	1,745	1,425	1,379	1,559	13.0%
Non industry	Commercial and institutional facilities	563	507	498	567	582	2.7%
	Residential facilities	701	667	618	641	698	9.0%
	Plants in agriculture, forestry and aquaculture	212	218	164	143	134	-6.3%
	Subtotal	1,477	1,392	1,280	1,351	1,415	4.7%
Manufacturing industry	Combustion facilities	65	84	57	67	130	94.6%
	Processes	245	309	229	233	254	8.9%
	Others	492	407	431	327	288	-11.9%
	Subtotal	803	800	717	627	672	7.1%
Industrial process	Petroleum industry	23,341	21,936	22,368	23,384	24,496	4.8%
	Iron and steel industry	1,523	1,531	1,691	1,728	1,728	0.0%
	Inorganic chemical industry	3,209					
	Ammonia consumption	9,933	11,584	13,984	14,320	16,265	13.6%
	Subtotal	38,006	35,051	38,043	39,432	42,489	7.8%
Road transport	Passenger cars	9,434	9,631	9,906	9,863	4,554	-53.8%
	Taxis					102	
	Vans	8	8	8	7	18	163.2%
	Buses	11	10	12	14	27	94.6%
	Freight cars	91	90	83	88	162	85.0%
	Special cars	2	2	2	2	3	28.4%
	RV	47	48	52	56	154	176.8%
	Two-wheeled vehicles	49	48	49	50	51	1.8%
	Subtotal	9,641	9,839	10,113	10,078	5,071	-49.7%
	Non-road transport	Railroads	19	16	14	12	11
Ships		113	114	13	14	14	6.5%
Agricultural machineries		54	54	53	53	53	0.0%
Construction machineries		29	37	36	38	39	3.6%
Subtotal		214	220	116	117	117	0.7%
Waste	Others	24	23	23	22	22	0.8%
Agriculture	Fertilizer use	23,267	21,691	20,172	19,901	19,553	-1.7%
	Manure management	215,707	209,426	207,781	211,362	217,464	2.9%
	Subtotal	238,975	231,117	227,953	231,263	237,017	2.5%
Others	Animals	12,737	12,785	12,832	12,882	12,924	0.3%
Biomass burning	Open burning	3	3	2	2	2	-2.8%
	Agricultural residue incineration	5	5	5	5	5	3.0%
	Wood stoves and boilers	10	10	6	6	6	-1.1%
	Furnace	3	3	2	2	2	-1.8%
	Subtotal	20	20	16	15	15	-0.1%
Total		303,483	292,993	292,517	297,167	301,301	1.4%