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# Analysis of Air Pollutant Emissions from Agricultural Machinery in South Korea

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# 국내의 농업기계에 의해 배출되는 대기 오염 물질 분석

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## ABSTRACT

From 2019 onwards, more stringent regulations (from Stage 4 to Stage 5) are to be implemented in Europe in order to reduce the air pollutant emissions. In South Korea, the government authorities started to make new regulation to meet the European regulation. As a first step, the air pollutant emissions such as CO, NOx, SOx, TSP, $PM_{10}$, $PM_{2.5}$, VOC, $NH_3$ by agricultural machinery were analyzed based on CAPSS inventory along with the analysis in the general aspect in this study. Three levels of analysis was conducted each in agricultural machinery aspect along with in the general aspect. Per agricultural tractor, all kinds of the air pollutant emissions decreased by 25, 25, 99, 25, 25, 25, 25% for the CO, NOx, SOx, TSP, $PM_{10}$, VOC, $NH_3$ emissions each from the year 2000 to the year 2014. Per combine harvester, all kinds of the air pollutant emissions decreased by 63, 63, 91, 63, 63, 63, 63% for the CO, NOx, SOx, TSP, $PM_{10}$, VOC, $NH_3$ emissions each from the year 2000 to the year 2014.

**Keywords :** Agricultural Machinery(농업기계), Air Pollutant Emission(대기 오염 물질), Emission Reduction(배기가스 감소), Energy Saving(에너지 절감), Exhaust Gas Regulation(배기가스 규제)

## 1. Introduction

Emission of air pollutants from burning fossil fuels has become a major environmental and social issue across the world, even creating disputes between neighboring countries. Both the EU and the US have implemented regulations, such as ‘Stage’ and ‘Tier’ emissions regulations introduced in 1999 and 1996 respectively in the two regions, to define the acceptable limits for exhaust emissions from internal combustion engines. These regulations have been

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further updated and strengthened to limit emissions of air pollutants such as nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). The emission restrictions in the EU are to become more stringent (Stage 5) from 2019.

Likewise, the government authorities in South Korea are preparing to implement similar regulations with respect to air pollutant emissions to uphold their environmental responsibility in the global arena, as well as be competitive in the industrial sector. Agricultural machinery such as tractors and combine harvesters, along with construction equipment, are also likely to be regulated under the new limitations. Although there have been studies that have evaluated the energy efficiency of agricultural machinery, there has been no study that has made an attempt to analyze their contribution to emission of domestic air pollutants in South Korea[1-4]. Agricultural machines such as tractors and combine harvesters are classified as mobile emission sources, based on the classification of emissions according to their sources as point sources, area sources, and mobile sources. Also, there have been numerous studies or monitoring of air quaility including $PM_{10}$[5].

Meanwhile, the emissions from fossil fuel combustion can be categorized into the following two types - greenhouse gases such as carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), sulfur hexafluoride ($SF_6$), hydrofluorocarbons (HFCs), and perfluorinated compounds (PFCs) that are related to climate change, and air pollutants such as CO, sulfur oxide (SOx), total suspended particles (TSP), volatile organic compounds (VOCs), ammonia ($NH_3$), NOx, and particulate matter - $PM_{10}$ and $PM_{2.5}$. Among them, NOx such as nitrogen dioxide ($NO_2$) mainly originate from oxidative reactions in the atmosphere, and play a significant role in the formation of ozone ($O_3$).

Air pollutant emissions pose serious social problems in various aspects, including their adverse impact upon human health. Particulate matter such as $PM_{2.5}$ and $PM_{10}$ has become a major issue in South Korea because of their role in causing respiratory diseases[6-7]. Additionally over the recent decades, air pollutants such as NOx, have been suspected to be potential aggravating factors of a topic eczema, asthma, and hay fever affecting pre-school children (5-6 years old) all across the world[8-9].

Efforts have been made by many experts to reduce air pollutant as well as greenhouse gas emissions[10]. As a first step towards reduction of air pollutants, analysis of their emission status needs to be done in a similar manner as the estimation of $CO_2$ emissions were done[11]. As of December 2018, agricultural tractors and combine harvesters should follow the emission regulation along with construction machinery in South Korea. In South Korea, Tier 4 level of emission regulation has been enforced upon agricultural tractors and combine harvesters using engines below 56 kW, and in the range between 130 kW and 560 kW, since January 1st, 2015. A year later from January 1st, 2016, this range was extended to include engines between 56 kW and 130 kW.

At present, there are various technologies, such as exhaust gas recirculation (EGR), diesel particulate filter (DPF), selective catalyst reduction (SCR), and diesel oxidation catalyst (DOC) to reduce pollutant emissions from non-road engines. Kim et al.[12] reported pre-treatment technologies and emission characteristics for non-road engines to meet the Tier 4 regulations. Cho et al.[13] evaluated reduction of emissions from diesel engines in off-road vehicles through attachment of turbo chargers to the 4 cylinder 3400 cc diesel engines.

In the past two decades, annual emission trends of air pollutants by region in South Korea have been reported in the Clean Air Policy Support System (CAPSS) inventory[14]. Similarly, there have also been reports on the emission regulations for fine dust including $PM_{2.5}$ and $PM_{10}$[15]. However, there has been no analysis on the annual emission trends of air pollutants from agricultural machinery in South Korea. On the contrary, the same has been reported from the US and EU, focusing on the emission control programs for non-road diesel engines and agricultural machinery in the two regions[16].

In this study, air pollutant emissions were analyzed for non-road vehicles that come under the new emission regulations such as agricultural tractors and combine harvesters from different perspectives, as a first step to enable the agricultural machinery industry prepare for the stricter regulations. It can be noted here that the agricultural machinery in South Korea investigated for air pollutant emissions in this study pertains only to the non-road vehicles.

## 2. Research Approach

### 2.1 Research scope

Figure 1 displays the various researches conducted in the area of energy saving and emission reduction in agricultural machinery in South Korea[1-4,11,17]. The studies concerning energy efficiency classification and estimation of CO2 emissions were done for agricultural tractors, agricultural heaters, agricultural dryers, and grain dryers, wherein 88.6% of the total tax-free fuels were allocated to these kinds of machines for agricultural use in South Korea[18]. The study on economic analysis based on energy efficiency grades was conducted for agricultural tractors. However, till date, there has been no study on air pollutant emissions from agricultural machinery. Thus, this study may be able to be positioned at the concept design and introduction into agricultural machinery area towards the multidisciplinary research at the diverse perspective.

### 2.2 Research materials and methods

In this study, air pollutant emissions were first analyzed in general at three different levels: firstly by their source category, secondly by the type of air pollutant, thirdly by the year of emission. Again,

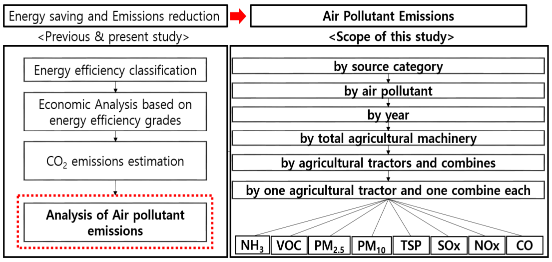



**Fig. 1 schematic representation of research conducted on energy saving and emission reduction in agricultural machinery by previous and the present study, and flow of analysis followed in this study**

based on the agricultural machinery, air pollutant emissions were analyzed at three levels: firstly by the total agricultural machinery, secondly by agricultural tractors and combine harvesters, and lastly by one agricultural tractor and one combine harvester. In the first level of the general air pollutant emissions, the different categories of emission sources were considered according to the classification in CAPSS for 8 kinds of air pollutants (CO, NOx, SOx, TSP, $PM_{10}$, $PM_{2.5}$, VOC, $NH_3$)[19-21]. In the second level, eight types of agricultural machines (cultivator, sprayer, water pump, thresher, sower, rice transplanter, tractor, and combine harvester)[19-21] were considered to measure the emission of air pollutants, as per the official statistics of the Ministry of Environment, South Korea, published in the CAPSS emission inventory. Also, the following two kinds of agricultural machines - agricultural tractor and combine harvester, which were particularly brought under the emission regulations in South Korea as of 2018, were specifically analyzed.

## 3. Research Results and Discussions

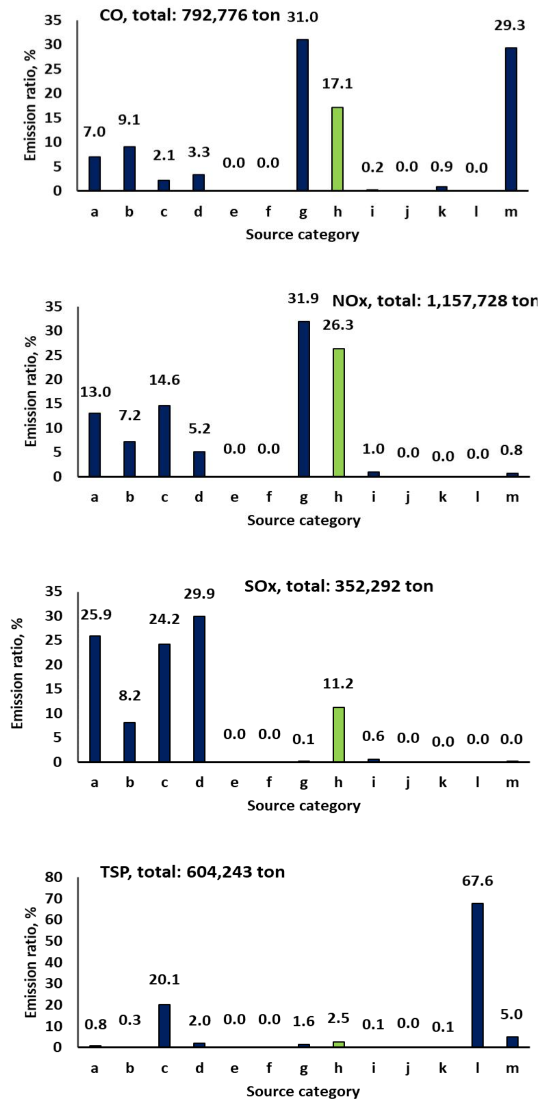
### 3.1 Air pollutant emissions by source category

In the EU, greenhouse gas inventories and air pollutant emission inventory system have been classified mainly according to the CORINAIR (Core Inventory of Air Emissions) and IPCC (Intergovernmental Panel on Climate Change) methodologies[22]. The CORINAIR 1985 inventory, which is an inventory of air pollutant emissions in Europe, covered eight primary source sectors: combustion, oil refineries, industrial combustion, processes, solvent evaporation, road transportation, nature, and miscellaneous[10]. In South Korea, the CAPSS inventory was formed based on the Selected Nomenclature for sources of Air Pollution (SNAP 97) of the CORINAIR nomenclature.

Figure 2 displays the emission pattern of eight types of air pollutants (CO, NOx, SOx, TSP, $PM_{10}$, $PM_{2.5}$, VOC, $NH_3$), as a ratio of the total emissions from 13 different kinds of source categories in 2015.

The CO emissions were found to be the highest from the road transportation source category (31%), followed by biological combustion (29.3%), and non-road transportation sources (17.1%). Road transportation accounted the highest NOx emissions at 31.9% emission ratio, followed by the non-road transportation source (26.3%). The SOx emissions were highest from production processes (29.9%), followed by combustion in energy production (25.9%). The largest TSP emissions were recorded from the waste disposal sector (67.6%), followed by the combustion in manufacturing industry category (20.1%). Fugitive dust was the dominant source of PM10 emissions (47.0%), while combustion in the manufacturing industry constituted the second largest source (30.4%). Alternately, with regards to $PM_{2.5}$ emissions, the combustion in manufacturing industry category was observed to be the largest source (36.8%), while fugitive dust was the second largest (17.5%). The VOC emissions were highest from the solvent utilization sources (54.9%), followed by the production process category (18.1%). Lastly, agriculture sources contributed highest to $NH_3$ emissions, followed by the production process source (13.3%).

The non-road transportation source category involving agricultural machinery accounted for 26.3% of the total NOx emissions, 17.1% of the total CO emissions, 14.3% of the total $PM_{2.5}$ emissions, 11.2% of the total SOx emissions, 6.6% of the total $PM_{10}$ emissions, 4.0% of the total VOC emissions, 2.5% of the total TSP emissions, and none for $NH_3$ emissions.



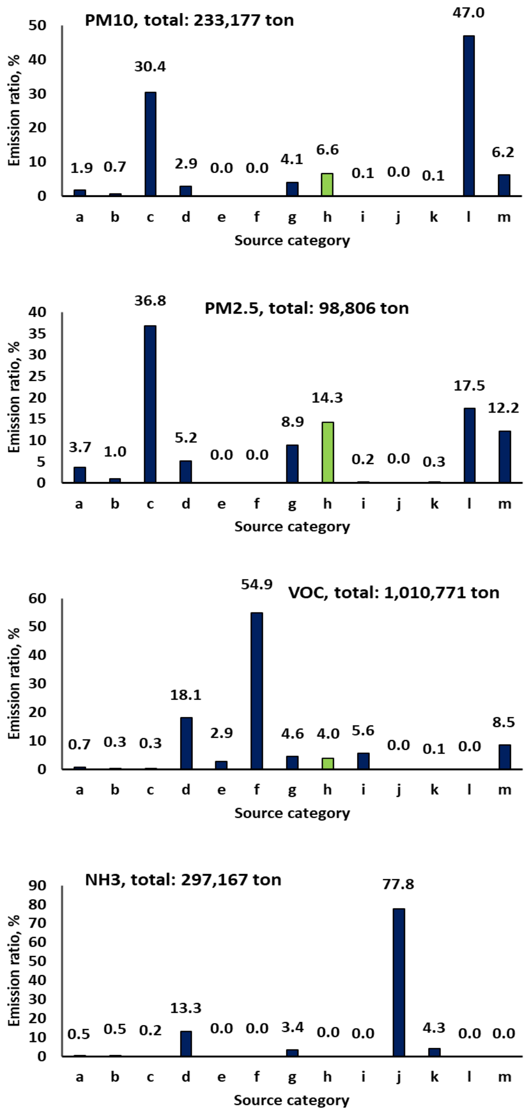



**Fig. 2 Air pollutant emissions in South Korea by source categories in 2015 (a = combustion in energy production, b = non-industrial combustion, c = combustion in manufacturing industry, d = production processes, e = energy storage & transport, f = solvent utilization, g = road transportation, h = non-road transportation, i = waste disposal, j = agriculture, k = other sources, l = fugitive dust, m = biological combustion)**

## 3.2 Air pollutant emissions by the type of the pollutant

Eight types of air pollutant emissions (CO, NOx, SOx, TSP, $PM_{10}$, $PM_{2.5}$, VOC, $NH_3$) were analyzed for 11 source categories for the year 2014.

This paper specifically focused on the air pollutant emissions from non-road transportation sources, given the categorization of agricultural machinery under non-road transportation. In addition, these were compared with emissions from the road transportation sector to distinguish between emissions from the two sectors.

In the case of the road transportation sector, the highest and second highest ratios were obtained for NOx and CO emissions at 50% and 39% respectively as shown in Fig. 3. This ratio was comparatively higher in the case of the non-road transportation sector, wherein ratio of the NOx emissions was 54% and 23% for CO emissions.

The NOx, $PM_{10}$, $PM_{2.5}$ emissions by ‘non-road transportation’ source were 81%, 148%, 148% each compared to those by ‘road transportation’ source.

## 3.3 Air pollutant emissions by year

The number of emission sources recognized in the CAPSS inventory system changed from 11 to 13 in 2007 considering the changing domestic scenario. However, the air pollutant emissions by year in this study have been analyzed for 11 air pollutant emission sources, excluding the fugitive dust and biological combustion sources.

From Fig. 4, it could be observed that from 1999 to 2014, emissions of five air pollutants, namely NOx, TSP, $PM_{10}$, VOC, and $NH_3$ exhibited an increase, while emissions of CO, SOx, and $PM_{2.5}$ decreased. The measurements for $PM_{2.5}$ began from 2011 onwards; therefore, there is no emission data for it prior to 2011.

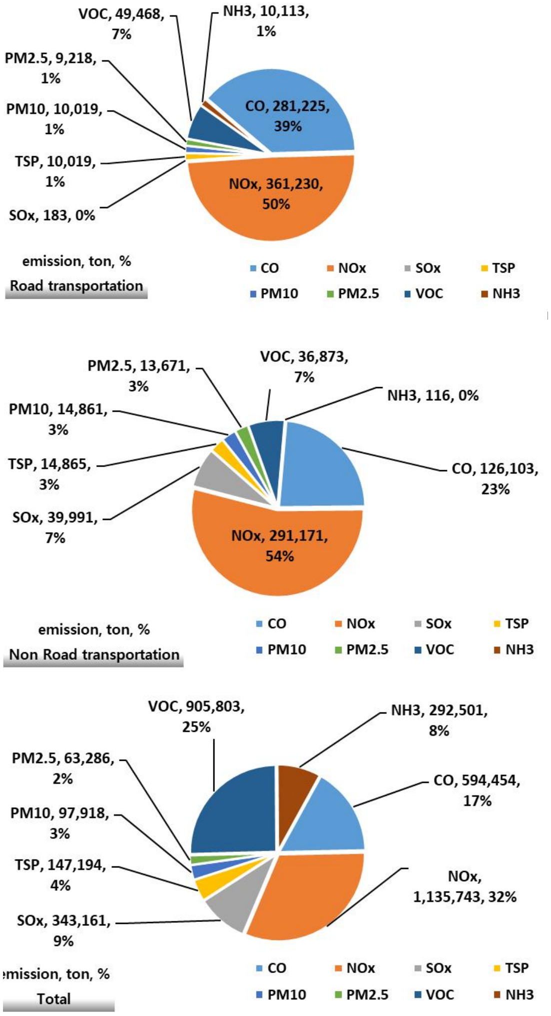



**Fig. 3 Air pollutant emissions by source category in 2014**

The emission of CO decreased from 885 kt in 1999 to 594 kt in 2014, while SOx emissions decreased from 485 kt in 1999 to 343 kt in 2014. Similarly, between 2011 and 2014, the $PM_{2.5}$ emissions decreased from 82 kt to 63 kt. Amongst the emissions that increased, NOx displayed an overall increase from 1999 (1072 kt) to 2014 (1136 kt), although there was a phase of decrease in

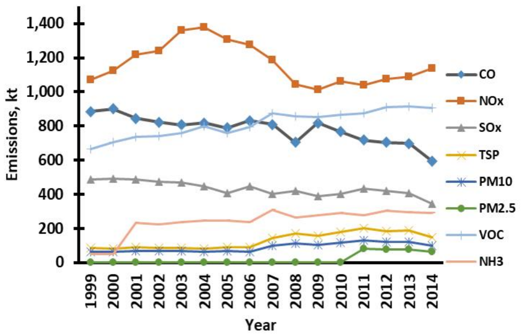



**Fig. 4 Air pollutant emissions in South Korea by year**

between, from 1378 kt in 2004 to 1014 kt in 2009. Likewise, the TSP emissions increased from 85 kt in 1999 to 147 kt in 2014, and specifically incrased sharply between 2006 and 2007 from 88 kt to 145 kt, respectively. The $PM_{10}$ emissions increased from 63 kt in 1999 to 98 kt in 2014, even though it decreased from 122 kt in 2013 to 98 kt in 2014. The VOC emissions increased from 665 kt to 906 kt between 1999 and 2014, while $NH_3$ emissions increased from 50 kt to 293 kt between the two years.

Over the 15 years from 1999 to 2014, only two air pollutant emissions – CO and SOx displayed a decrease of 49% and 41% respectively, while the others increased by 6% for NOx, 52% for TSP, 35% for $PM_{10}$, 27% for VOC, and 83% for $NH_3$. Emissions of $PM_{2.5}$ decreased by 29% during the period from 2011 to 2014.

It can be observed that the $PM_{10}$ emissions increased by 37% between 2000 and 2014, even though their emission from the eight kinds of agricultural machinery decreased by 28% during the same period. This could possibly be explained from the fact that particulate air pollutants such as $PM_{2.5}$ and $PM_{10}$ originate mainly from coal combustion[23], and the ratio of coal-fired electrical power plants in South Korea increased from 7.3% in 1981 to 48.3% in 2015[24].

Amongst the air pollutant emissions by non-road transportation, the emissions of all examined air pollutants other than $NH_3$ from agricultural machinery decreased, as shown in Fig. 5. Accordingly, the ratio of emissions between 1999 and 2014 decreased from 21.1% to 5.7% for CO, 13.3% to 5.6% for NOx, 0.9% to 0.0% for SOx, 22.6% to 8.8% for TSP, 25.5% to 9.2% for $PM_{10}$, 10.0% to 9.2% for $PM_{2.5}$, 16.5% to 5.3% for VOC. Conversely, $NH_3$ emissions increased from 16.5% in 1999 to 46.0% in 2014. The reason why the emission ratio of all air pollutants from agricultural machinery other than $NH_3$ decreased could either be the technical evolution in such machinery or the reduction in their usage time.

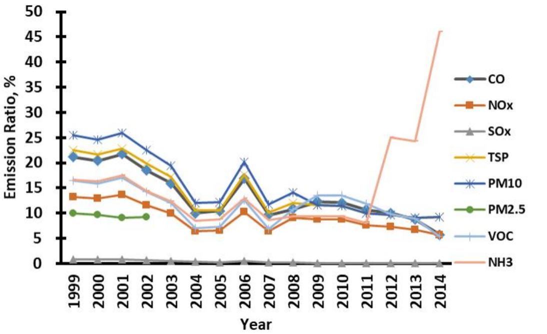



**Fig. 5 Year-wise ratio of air pollutant emissions from agricultural machinery amongst non-road transportation in South Korea**

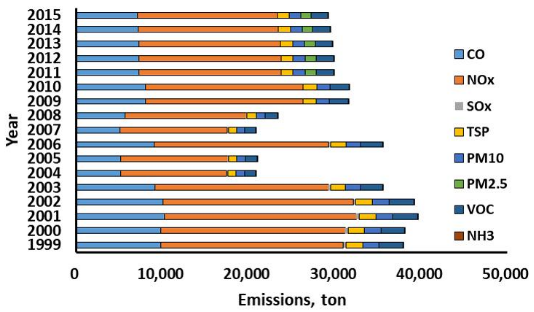



**Fig. 6 Air pollutant emissions by total agricultural machinery in South Korea by year**

## 3.4 Air pollutant emissions by total agricultural machinery

In South Korea, the aviation, locomotive, marine sectors are the sources that are associated with agricultural machinery and construction equipment in the non-road transportation pollutant source category.

In this study, the air pollutant emissions from eight types of agricultural machinery (i.e., cultivator, combine harvester, sprayer, water pump, thresher, sower, tractor, and rice transplanter), which have been reported in South Korea from the year 1999[25] were analyzed year-wise from 1999 to 2015, as displayed in Fig. 6.

The CO emissions decreased form 9,780 ton in 1999 to 7,097 ton in 2015. Similarly, between 1999 and 2015, the NOx emissions decreased from 21,196 ton to 16,209 ton, the SOx emissions decreased from 340 ton to 4 ton, the TSP and $PM_{10}$ emissions decreased from 1,901 ton to 1,348 ton, $PM_{2.5}$ decreased from 1,281 ton to 1,240 ton, VOC emissions decreased from 2,757 ton to 1,933 ton., and lastly, $NH_3$ emissions decreased from 67 ton to 53 ton.

## 3.5 Air pollutant emissions by agricultural tractors and combine harvesters

Fig. 7 exhibits the emissions of the eight air pollutants by both agricultural tractors and combine harvesters. The CO emissions increased from 1,724 ton in 1999 to 2,630 ton in 2008, followed by a decrease to 1,872 ton in 2015.

A similar pattern was observed in the emission of NOx, which increased from 5,084 ton in 1999 to 7,923 ton in 2008, followed by a decrease to 5,759 ton in 2015. The SOx emissions decreased sharply from 121 ton in 1999 to 2 ton in 2015. The TSP and $PM_{10}$ emissions increased from 290 ton in 1999 to 434 ton in 2008, and then decreased to 302 ton in 2015. The $PM_{2.5}$ emissions were 278 ton in 2015. The VOC emissions increased from 341 ton in 1999

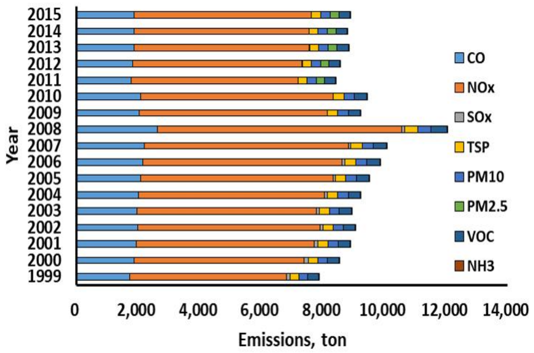



**Fig. 7 Air pollutant emissions by agricultural tractors and combine harvesters in South Korea by year**

to 516 ton in 2008, decreasing to 365 ton in 2015. The $NH_3$ emissions ranged between 20 and 31 ton from 1999 to 2015.

The ratio of the NOx emissions from agricultural tractors and combine harvesters among agricultural machinery increased from 24% in 1999 to 36% in 2015. The ratio of PM10 emissions by the same increased from 15% in 1999 to 22% in 2015, while emission of PM2.5 increased from 21% in 2011 to 22% in 2015.

Amongst the eight agricultural machines, the agricultural tractors and combine harvesters displayed highest emissions during the year - 2008, 2007, 2005, and 2004 compared to all other examined years (Fig. 8). At the same time, the air pollutant emissions by total agricultural machinery were relatively smaller during the same years, as can be observed in Fig. 5. The uncertainty in the data of the CAPSS emission inventory[26] might be one of the possible reasons for the occurrence of the peaks in Fig. 8.

## 3.6 Average annual air pollutant emissions per agricultural tractor and per combine harvester

The air pollutant emissions per agricultural tractor and combine harvester can be obtained by dividing the air pollutant emissions by the total number of agricultural tractors and combine harvesters supplied in South Korea[27]. The air pollutant emissions by a single agricultural tractor and a single combine harvester per year are shown in Fig. 9.

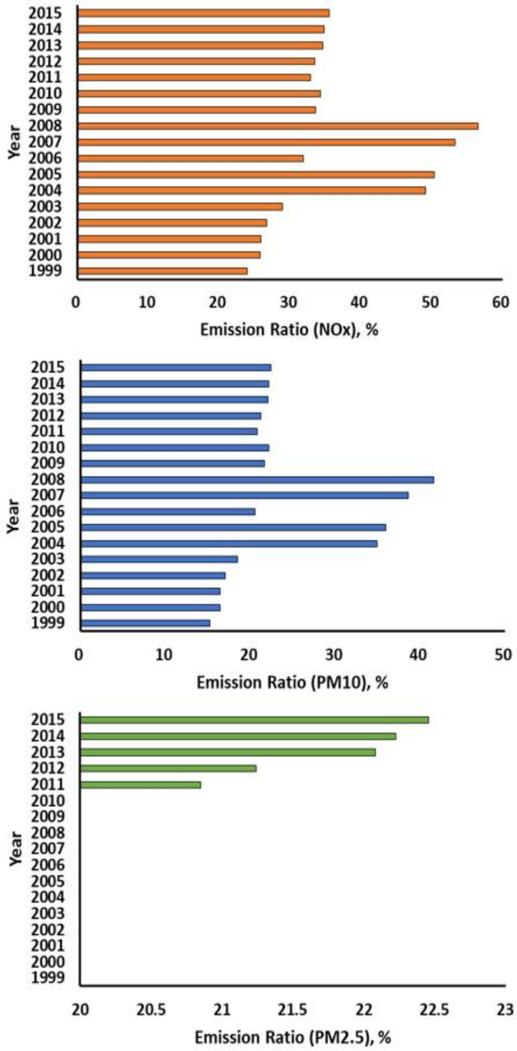



**Fig. 8 Air pollutant emissions by agricultural tractors and combine harvesters amongst air pollutant emissions by total agricultural machinery in South Korea by year**

Per agricultural tractor, the CO emissions decreased from 8.235 kg in 2000 to 6.155 kg in 2014, NOx from 26.033 kg to 19.457 kg, SOx from 0.607 kg to 0.006 kg, TSP from 1.295 kg to 0.968 kg, $PM_{10}$ from 1.295 kg to 0.968 kg, VOC from 1.594 kg to 1.191 kg, and $NH_3$ from 0.100 kg to 0.074 kg. Meanwhile, based on the four years of available record on $PM_{2.5}$ emissions, they increased slightly from 0.877 kg in 2011 to 0.891 kg in 2014.

With regards to per combine harvester, between 2000 and 2014, the CO emissions decreased from 1.507 kg to 0.559 kg, NOx from 2.786 kg to 1.033 kg, SOx from 0.080 kg to 0.000 kg, TSP from 0.337 kg to 0.125 kg, $PM_{10}$ from 0.337 kg to 0.125 kg, VOC from 0.329 kg to 0.122 kg, $NH_3$ from 0.013 kg to 0.005 kg. Likewise, the $PM_{2.5}$ emissions decreased marginally from 0.121 kg in 2011 to 0.115 kg in 2014

Due to the lower usage time of combine harvesters as compared to tractors, the yearly air pollutant emissions per combine harvester were smaller than that by one tractor.

To reduce harmful air pollutant emissions from agricultural tractors and combine harvesters, there are certain ways, such as teaching the drivers to improve driving efficiency, eco-driving for bus and truck drivers[28], simulating training courses[29-30], as well as implementation of pre-treatment and post-treatment technologies. In the area of agricultural machinery, there is the need for more in-depth and continuous research on the various aspects surrounding agricultural works[31-38] in order to reduce air pollutant emissions from such sources. Along with this, it is also essential to continuously monitor the status of the air pollutant emissions.

## 4. Summary and Conclusions

This study analyzed the emission of air pollutant emissions such as $NH_3$, VOC, $PM_{2.5}$, $PM_{10}$, TSP, SOx, NOx, and CO, measured and reported officially

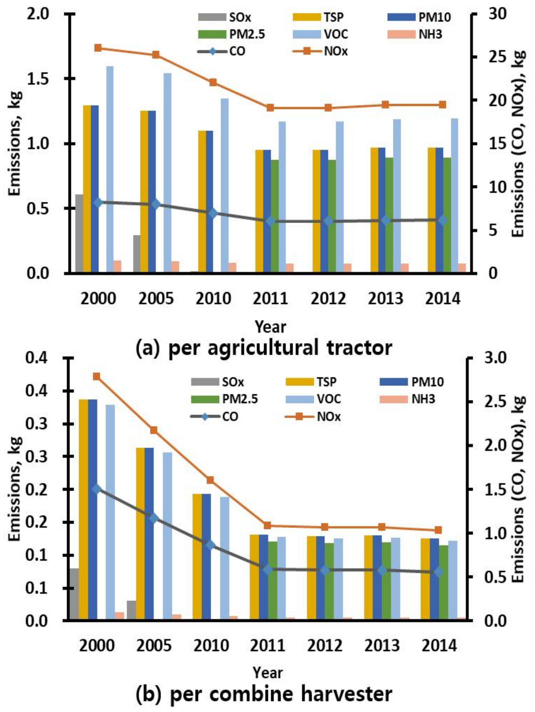



**Fig. 9 Air pollutant emissions per agricultural tractor and per combine harvester in South Korea by year**

in the CAPSS inventory system of South Korea, in general, as well as from the perspective of agricultural machinery. In the overall general evaluation, the air pollutant emissions were analyzed at 3 levels: by emission source category, by the type of air pollutant, and by the year of emission. In terms of agricultural machinery, the air pollutant emissions were analyzed by total agricultural machinery, by agricultural tractors and combine harvesters, and by one agricultural tractor and one combine harvester.

Based on this study's analysis of the emission of air pollutants by agricultural tractors and combine harvesters, it can be stated that the plans to meet the new regulations for reduction of air pollutant emissions can be established nationally with respect to the agricultural machinery sector.

## Acknowledgements

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