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Quantitative assessment of industrial VOC emissions in China: Historical trend, spatial distribution, uncertainties, and projection

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HIGHLIGHTS

- An updated industrial VOCs emission inventory was developed for 2011–2013 in China.
- Variations in regions and source characteristics were investigated and analyzed.
- Scenario were set to project industrial VOCs emissions for the year 2020, 2030 and 2050, which present the potential of the emissions reduction.

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ABSTRACT

The temporal trends of industrial volatile organic compound (VOC) emissions was comprehensively summarized for the 2011 to 2013 period, and the projections for 2020 to 2050 for China were set. The results demonstrate that industrial VOC emissions in China increased from 15.3 Tg in 2011 to 29.4 Tg in 2013 at an annual average growth rate of 38.3%. Guangdong (3.45 Tg), Shandong (2.85 Tg), and Jiangsu (2.62 Tg) were the three largest contributors collectively accounting for 30.4% of the national total emissions in 2013. The top three average industrial VOC emissions per square kilometer were Shanghai (247.2 ton/km^2), Tianjin (62.8 ton/km^2), and Beijing (38.4 ton/km^2), which were 12–80 times of the average level in China. The data from the inventory indicate that the use of VOC-containing products, as well as the production and use of VOCs as raw materials, as well as for storage and transportation contributed 75.4%, 10.3%, 9.1%, and 5.2% of the total emissions, respectively. ArcGIS was used to display the remarkable spatial distribution variation by allocating the emission into 1 km × 1 km grid cells with a population as surrogate indexes. Combined with future economic development and population change, as well as implementation of policy and upgrade of control technologies, three scenarios (scenarios A, B, and C) were set to project industrial VOC emissions for the years 2020, 2030, and 2050, which present the industrial VOC emissions in different scenarios and the potential of reducing emissions. Finally, the result shows that the collaborative control policies considerably influenced industrial VOC emissions.
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1. Introduction

According to the Greenpeace East Asia's 2015 annual city rankings, the average $PM_{2.5}$ concentration in 189 cities around China fell by 10% compared to that in 2014. However, physicists at the University of California, Berkeley, calculated that about 1.2–2.0 million people in China died annually of heart, lung, and stroke problems because of the incredibly polluted air (Rohde and Muller, 2015). Data analysis results showed that 92% of the Chinese population experienced >120 h of unhealthy air (US EPA standard), and 38% on average experienced unhealthy concentrations (Rohde and Muller, 2015). Therefore, improving air quality remains to be a serious issue in China. The most recent research from the Institute of Earth Environment, Chinese Academy of Sciences shows that secondary aerosols (produced through a complex interaction of sunlight; volatile organic compounds from trees, plants, cars, or industrial emissions; and other airborne chemicals (EPA, 2016)), in particular secondary organic aerosol, contribute about 25% to the formation of fine particle pollution during haze events (Huang et al., 2014). Recently, many studies focused on the emission of anthropogenic

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Table 1
Source classification, activity data, and data sources of the industrial VOC emission inventory.

Source	Source	Activity data	Reference
Production of VOCs	Crude oil and natural gas exploration	Crude production	National Bureau of Statistics of China
		Natural gas production	
	Petroleum refining	Tank loss	
		Transport loss	
		Leakage loss	
		Volatile refining wastewater	
	Basic chemical raw materials manufacturing	Ethylene	
		Methyl alcohol	Nitrogen Fertilizer Industry Association of China
		Benzene	ASKCI Corporation Database
		Synthesis ammonia	National Bureau of Statistics of China
Storage and transport	Storage & transportation of crude oil	Production/Import/Export	
	Storage & transportation of gasoline	Production/Import/Export	
	Storage & transportation of other oil	Production/Import/Export	
	Storage & transportation of solvent	Production/Import/Export	ASKCI Corporation Database
Industrial processes using VOCs as raw materials	Manufacture of paint		
	Manufacture of printing		Printing and Printing Equipment Industries Association of China
	Primary form of plastic	Polyethylene resin	National Bureau of Statistics of China
		PVC resin	
		ABS resin	
		Other resin	
	Synthetic rubber		
	Synthetic fiber	Polyester	
		Chinlon	
		Acrylic	
		Vinylon	
		Spandex	
		Cellulose	
		Other fibers	
	Manufacture of adhesive	Three-formaldehyde and other adhesives	China Adhesives and Tape Industry Association
		Water-based adhesive	
	Manufacture of food & drink	Vegetable oil refining	National Bureau of Statistics of China
		Sugar refining	
		Fermentation alcohol	ASKCI Corporation Database
		Wine	
		Beer	National Bureau of Statistics of China
	Chemical raw materials		
	Chemical pesticide		
	Manufacture of commodity	Synthetic detergent	
	Tire		
Use of VOCs-containing products	Textile dyeing	Textile dyeing	China Dyestuff Industry Yearbook
	Synthetic leather	PU size	Reference (Shen et al., 2005)
	Shoemaking leather	Shoe adhesive	China Adhesives and Tape Industry Association
	Printing industry	Planographic printing	China Dyestuff Industry Yearbook
		Gravure printing	
		Relief printing	
		Porous printing	
		Other printing	
		Packaging adhesive	China Adhesives and Tape Industry Association
		Binding adhesive	
	Wood processing	Wood adhesive	
	Furniture	Wood paintings	Reference (Jianhong, 2011)
	Machinery equipment manufacturing	Other paintings	ASKCI Corporation Database
		Assembling adhesive	China Adhesives and Tape Industry Association
	Transportation equipment manufacturing	Transport equipment manufacturing adhesive	
	Architectural ornament	Coating for interior walls	China Building Material Federation
		Coating for other building	
		Wood paintings	Reference (Jianhong, 2011)
		Assembling adhesive	China Adhesives and Tape Industry Association
	Dry cleaning of clothing	Tetrachloroethylene	Reference (Shang and Shen Ye, 2006)
	Electronic component manufacturing	Diode/Transistor	Development Research Center of the State Council database
		Printed circuit board(PCB)	Reference (Shanhong, 2008)
		Copper clad laminate	China Electronics Materials Industry Association (2014)
	Coke production	Coke	National Bureau of Statistics of China
	Paper production	Pulp products	ASKCI Corporation Database
		Paper products	
	Garbage pollution treatment	Sanitary landfill	National Bureau of Statistics of China
		Composting	
		MSW incineration	
	Thermal power	Coal	National Bureau of Statistics of China
		Fuel oil	
		Liquefied petroleum gas	
		Natural gas	

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