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Ammonia emissions from tobacco manufacturing in North Carolina: State-level trends and global implications

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Abstract

Tobacco manufacturing is a prominent industry in the state of North Carolina. The production of tobacco products results in the air emissions release of ammonia, which is used in tobacco manufacturing to "free-base" nicotine to facilitate faster absorption into the bloodstream. Ammonia is known to lead to health issues related to the cardiovascular system and is also a major element of Particulate Matter 2.5 ($PM_{2.5}$) in the atmosphere. It is deemed a pollutant by the Environmental Protection Agency (EPA). This study aimed to examine the effect of tobacco manufacturing in North Carolina on ammonia air emissions released from facilities that report to the EPA's Toxic Release Inventory (TRI). Tobacco production data from the United States Department of Agriculture (USDA) were utilized as a comparison to the TRI database, and the Kendall rank correlation coefficient and regression analysis were applied to analyze the relationship between production and emission. This research uncovered a strong positive 0.59 correlation between annual tobacco production and total ammonia air emissions. These findings provide important insights into the environmental impact of tobacco production, underscoring the need for continued monitoring and analysis of emission trends.

Keywords: Tobacco Manufacturing; Ammonia Air Emissions; North Carolina; Toxic Release Inventory (TRI); Agricultural Industry

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1. Introduction

North Carolina produces the most tobacco in the United States. While the number of American smokers has gone down, emissions from the production of tobacco products still pose a risk to people and the environment. State and federal legislative acts regulate the discharges and emissions from various industrial facilities, but there is no specific policy addressing ammonia emissions in the tobacco industry. In particular, ammonia is not covered by the Clean Air Act (CAA) but is monitored under the Environmental Protection Agency's (EPA) Toxic Release Inventory (TRI) database. This study addresses the impact of tobacco production on ammonia air emissions and the trends in North Carolina.

2. Literature review

Since the 1860s, agriculture in the United States of America has transformed from small-scale farming to an advanced industry (Alston et al., 2009; Aspen, 2019; Blesh et al., 2023). In the 1900s, the agricultural industry accounted for about 22% of the US economy, as farming was a major industry for labor (Cai, 2019). In 2021, the agricultural industry, including food production and related industries, accounted for just 5.1% of the economy (Beckman and Countryman, 2021). Although the economic impact has decreased significantly compared to the past, modern advancements in machinery and transportation have allowed larger farms to modernize and specialize (Carlisle et al., 2019). Agriculture is not limited to the value of crops and livestock but serves as a crucial foundation for various industries, such as apparel, food manufacturing, and retail, which generate additional economic value (Bazargani and Deemyad, 2024).

The agricultural industry is a major source of greenhouse gas emissions (Bennetzen et al., 2016; Afrouzi et al., 2023). During the planting process, the use of fertilizers significantly contributes to the release of carbon emissions (Kuang et al., 2024). Other activities such as forage and manure management during livestock production also result in carbon emissions (Yue et al., 2017). Moreover, transporting agricultural products domestically or internationally to processing facilities results in carbon-powered fuel emissions that have detrimental effects on air quality (Al-Mansour and Jejcic, 2017; Escobar et al., 2020; Gustafsson et al., 2021).

Tobacco is one of many agricultural products cultivated and consumed by people in the US (Meza et al., 2023). The history and origins of tobacco extend beyond the year 1492, as it was already widely cultivated by Native American tribes before Columbus arrived in the New World (Hancock, 2022). By the seventeenth century, tobacco had spread across Europe through the Columbian Exchange (Nunn and Qian, 2010). Maryland and Virginia were major cultivators and exporters of the cash crops established by Britain during the colonial era (Wells, 2023). Large-scale production of these crops in America, facilitated by the labor of enslaved people between the seventeenth and nineteenth centuries, led to sizeable profits in the tobacco industry (Herbin-Triant, 2017; McMahon, 2022).

In North Carolina, tobacco played a particularly significant role in the economy (Johnson, 2020). Following the Civil War, there was an increase in demand for tobacco products such as cigarettes, which further solidified its importance to the state's economic landscape. Entrepreneurs including James B. Duke and R. J. Reynolds transformed cities like Durham and Winston-Salem into urban centers for tobacco production, leveraging advancements in railroad transportation and manufacturing techniques (Biles, 2007).

The spread and prevalence of tobacco increased through trade and consumption up until the twentieth century (Wipfli and Samet, 2016). The mass marketing of cigarettes towards the end of the nineteenth century popularized smoking in the USA (Proctor, 2012). By the mid-twentieth century, empirical evidence from scientific studies proved that cigarette smoking was a significant cause of lung cancer. The Surgeon General's report released in 1964 highlighted the health risks of smoking, leading to a significant decrease in the number of smokers and, consequently, a reduction in the demand and production of tobacco leaves in the United States (Klein and Resnick, 2021; Martins-da-Silva, 2022; Tam et al., 2023). Despite the reduction in the number of smokers, around 46 million people still used tobacco products in the United States in 2021 (Cornelius et al., 2023).

North Carolina remains one of the major producers of tobacco in the United States (Holford et al., 2023). The main tobaccos produced in North Carolina are burley and flue-cured tobacco, which have distinct aromas and flavors (Edwards, 2005). The tobacco industry in North Carolina has continued to flourish due to low excise taxes set at just 45 cents (Herndon et al., 2022) that allow residents to purchase tobacco products at lower costs compared to other states. Nevertheless, although the tobacco industry generated $647 million for North Carolina in 2016, this figure was not substantially greater compared to other agricultural products such as grains and sweet potatoes (Mills et al., 2018). This indicates that the tobacco industry in North Carolina has declined, and the growth of other industries has diversified the state's economic status, resulting in less reliance on tobacco revenue and a more balanced economic landscape (Jackson and Perret, 2018). Two major policies that have affected the tobacco industry were the Master Settlement Agreement (MSA) of 1998 and the tobacco buyout program in 2004 (Jayawardhana et al., 2014; Normann, 2019). These acts decreased tobacco marketing opportunities and revoked the existing quota system, reducing the incomes of farm owners (Fallin and Glantz, 2015). In particular, the MSA held large tobacco companies accountable for the lethal effects of smoking, leading to significant financial settlements.

Using tobacco products is known to increase cancer and other health risks, but it is also important to consider the health hazards that arise from manufacturing these products (Hussain et al., 2014; Andreotti et al., 2017). In particular, the chemicals used in processing tobacco leaves in manufacturing facilities pose occupational exposure risks for employees (Uitti et al., 1998; Ho et al., 2002; Kabir and Barman, 2019). A significant chemical used in these facilities is ammonia (Braillon and Lang, 2017; Hendlin and Bialous, 2019), which may account for several health hazards ranging from respiratory irritation to dizziness to life-threatening health effects or even death (Anjana et al., 2018). Studies on animals have shown "that exposure to high levels of ammonia in air may adversely affect other organs, such as the liver, kidney, and spleen" (EPA, 2016). Other than health hazards, ammonia is a major atmospheric pollutant, contributing to the formation of particulate matter ($PM_{2.5}$) in the air (Van Damme et al., 2018; Gu et al., 2021; Wyer et al., 2022). $PM_{2.5}$, which is monitored by the EPA, refers to a mixture of liquid and solid particles that are less than 2.5 μm and may cause cardiovascular and respiratory diseases including death (Shi et al., 2015; Fiordelisi et al., 2017; Hime et al., 2018; Johnson et al., 2018).

Although animal husbandry and fertilizers are the highest ammonia emitters, industrial processes, including tobacco manufacturing, also contribute significantly (Meng et al., 2017; Zeng et al., 2018). Meng et al. (2017) showed that approximately 12.2% of ammonia emissions are from combustion and industrial processes, which includes sectors like tobacco manufacturing because it is an industrial activity that processes raw agricultural products, linking it to agriculture through its emissions and environmental impacts. This indicates that while industrial activities are not the largest source of ammonia emissions, they still play a notable role in contributing to ammonia air emission levels. Ammonia is primarily used to "free-base" nicotine in the tobacco leaves (Watson et al., 2015, p. 266). This process allows faster absorption into the bloodstream and enhances the flavor, elevating the smoking experience (Gupta et al., 2019). However, studies show that ammonia itself does not have a significant impact on the total nicotine absorbed into the bloodstream of smokers (McKinney et al., 2011; van de Nobelen et al., 2016). Yamamoto et al. (2022) found that higher temperature levels of heated tobacco products resulted in increased ammonia emissions. In addition to its use in free-basing nicotine, ammonia is also released into the air through secondhand smoke, contributing to the harmful chemicals inhaled by non-smokers (Naeem, 2015). This underscores the broader environmental and health impacts of ammonia emissions associated with tobacco use, extending beyond direct smokers to those exposed to secondhand smoke.

The United States Department of Agriculture (USDA) states that clear policies for ammonia emission regulations do not exist (Shaver et al., 2014). Weldon (2018) and Freeman (2019) explain the limitations of existing legislation in monitoring ammonia emissions in the agricultural and industrial sectors. The Resource Conservation and Recovery Act (RCRA) exempts the regulation of agricultural wastes that are returned to the soil as fertilizers, which means it does not specifically target ammonia emissions. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) considers ammonia a hazardous chemical but prioritizes cleanup and liability, and facilities are not required to report emissions unless they are severe. Additionally, the Fair Agricultural Reporting Method (FARM) Act exempts the reporting of air emissions from farm operations. The Clean Air Act (CAA) regulates air emissions for pollutants designated by the EPA, but ammonia is currently not included.

Modern technologies utilized to mitigate ammonia air emissions from agricultural processes include ventilation systems and the use of liquid spray consisting of oil and acidic water (Bist et al., 2023; Cao et al., 2023; Hussain, 2023). Moreover, the use of these agricultural mitigation technologies could potentially be adapted for industrial processes related to agriculture, offering a broader application in reducing ammonia emissions. Studying the ammonia air emissions from agriculture-related industrial operations provides insight into the factors that contribute to the decreasing $PM_{2.5}$ levels in North Carolina and helps to explain the broader trends in air quality improvement since 2010 (Cheng and Wang-Li, 2019; Bravo et al., 2022; EPA, 2024a). The lack of regulation regarding ammonia emissions represents a significant gap in the research on air quality. In both the agricultural and industrial sectors, the absence of established regulations for ammonia air emissions hinders the effectiveness of regular monitoring.

3. Methodology

According to Sarah Swenson, communications lead of the TRI Program, stakeholder engagement branch, Office of Chemical Safety and Pollution Prevention, the TRI tracks the annual chemical emissions from U.S. facilities (personal communication, August-December 2023). The EPA requires that "all facilities that use more than 10,000 pounds or process more than 25,000 pounds of any of the 650 TRI chemicals report their releases and waste management strategies" (Wilson et al., 2012, p. 1975). The total air emission values for all facilities that reported to the TRI database for the years 2010-2022 are used in this study. Total air emissions is the sum of stack and fugitive air emissions released into the air (EPA, 2024b). Stack air emissions are released through pipes or ducts, while fugitive air emissions are indirect releases such as through leaks or ventilation systems. Specifically, only the total air emissions for ammonia in North Carolina are considered for the purpose of this study (see Table 1).

Table 1. 2010 North Carolina tobacco manufacturing facility ammonia emission

10. FACILITY NAME	**11. FACILITY STREET**	**15. FACILITY ZIP CODE**	**41. PRIMARY NAICS CODE**	**78. CHEMICAL NAME**	**115. TOTAL AIR EMISSIONS**
ITG BRANDS	2525 E MARKET ST	27401	312221	Ammonia	5646.46
R J REYNOLDS TOBACCO CO TVILL	7855 KING TOBACCOVILLE RD	27050	312221	Ammonia	15287
R J REYNOLDS TOBACCO CO WHITAKER PARK	4040 REYNOLDS COURT	27105	312221	Ammonia	19424
ALLIANCE ONE SPECIALTY PRODUCTS LLC	605 S TARBORO ST ANNEX	27894	312229	Ammonia	1561
AMERICAN SNUFF CO LLC TAYLOR BROTHERS DIV	2415 S STRATFORD RD	27103	312229	Ammonia	2512
CRES TOBACCO CO INC	3000 BIG OAKS DR	27021	312210	Ammonia	2237
ALLIANCE ONE INTERNATIONAL INC	8958 W MARLBORO RD	27828	312210	Ammonia	8248
ALLIANCE ONE INTERNATIONAL INC	2400 STANTONSBURG RD	27894	312210	Ammonia	4810

Source: EPA (2024c)

The values under the total air emissions are summed to find the annual total air emissions for ammonia (see Table 2).

Table 2. North Carolina total ammonia air emissions (lb.)

Years	**Ammonia air emission (lb.)**
2010	59,725
2011	59,455
2012	65,493
2013	67,717
2014	64,914
2015	58,253
2016	48,656
2017	44,672
2018	37,430
2019	17,718
2020	16,404
2021	17,303
2022	9,209

Table 3. North Carolina flue-cured and light air-cured burley tobacco (lb.)

Years	**Flue-cured**	**Light air-cured burley**
2010	348,600,000	4,025,000
2011	248,000,000	3,565,000
2012	377,200,000	3,990,000
2013	360,000,000	2,660,000
2014	451,200,000	2,660,000
2015	378,400,000	1,850,000
2016	330,000,000	1,800,000
2017	358,600,000	1,440,000
2018	250,800,000	1,125,000
2019	234,000,000	700,000.00
2020	178,200,000	527,000.00
2021	252,000,000	400,000.00
2022	240,000,000	320,000.00

This study focuses on the total tobacco production in the state of North Carolina for the years 2010-2022 compared to the total ammonia air emissions (USDA, 2024; see Table 3). North Carolina produced flue-cured and light air-cured burley tobacco for the years studied. Only facilities that had the NAICS codes for tobacco manufacturing were considered during the data collection (see Table 4).

Table 4. Tobacco manufacturing NAICS codes

2007 NAICS	2012 NAICS	2017 NAICS	Index Entries for 312230
312229	312230	312230	Chewing tobacco manufacturing
312229	312230	312230	Cigar manufacturing
312221	312230	312230	Cigarettes manufacturing
312221	312230	312230	Imitation tobacco cigarettes, manufacturing
312229	312230	312230	Pipe tobacco, prepared, manufacturing
312229	312230	312230	Reconstituting tobacco
312229	312230	312230	Smoking tobacco (e.g., cigarette, pipe) manufacturing
312229	312230	312230	Snuff manufacturing
312210	312230	312230	Tobacco leaf processing and aging
312229	312230	312230	Tobacco products (e.g., chewing, smoking, snuff) manufacturing
31222	312230	312230	Tobacco products, imitation, manufacturing
312229	312230	312230	Tobacco sheeting services
312210	312230	312230	Tobacco stemming and redrying

Source: NAICS (2024)

The values for flue-cured and light air-cured burley tobacco were summed to find the annual tobacco production as shown in Model 1 and presented in Table 5. Figure 1 depicts the total weight (in lbs.) of tobacco production in North Carolina.

Model 1: $Total\ production(lb.) = Flue\ cured\ (lb.) + Light\ air\ cured\ burley\ (lb.)$

Table 5. North Carolina total tobacco production (lb.)

Years	Tobacco (lb.)
2010	352,625,000
2011	251,565,000
2012	381,190,000

Table 5. *Cont.*

Years	Tobacco (lb.)
2013	362,660,000
2014	453,860,000
2015	380,250,000
2016	331,800,000
2017	360,040,000
2018	251,925,000
2019	234,700,000
2020	178,727,000
2021	252,400,000
2022	240,320,000

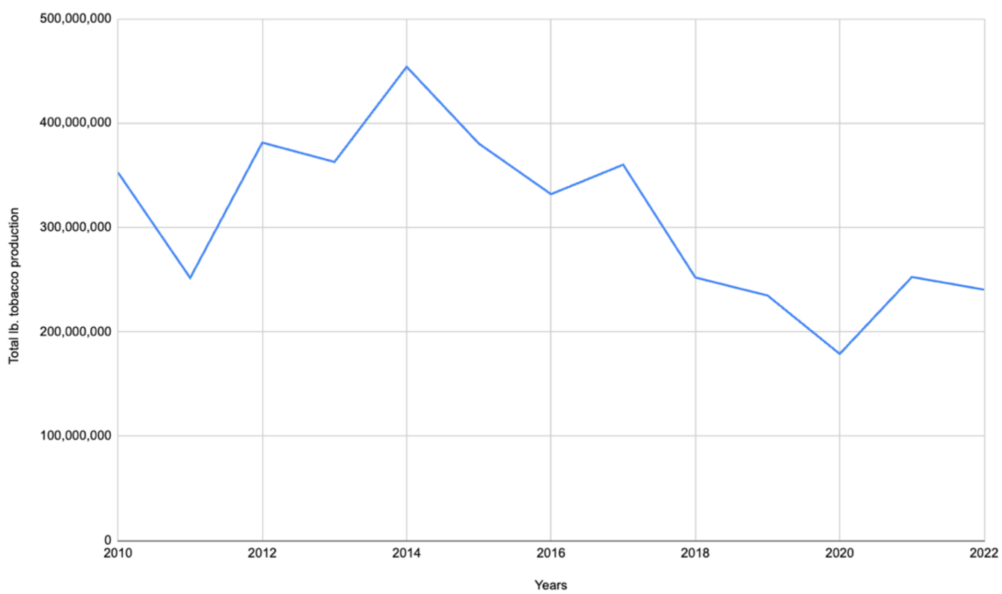

Figure 1. Total weight of tobacco production (lb.)

Ammonia emissions per lb. of production was calculated by dividing the total air emissions of ammonia by the total production weight of tobacco (see Model 2). The weighted emission values provide insight into the efficiency and environmental impact of tobacco production over the period under study.

Model 2: $$\frac{Ammonia\ emission\ per}{lb.\ of\ tobacco\ production_{year}} = \frac{Total\ ammonia\ air\ emissions\ (lb.)_{year}}{Total\ tobacco\ production\ (lb.)_{year}}$$

The Shapiro-Wilk test was used to verify the normality of the data of the total production and total emission values and therefore select the appropriate correlation test (Rebekić et al., 2015). The p-value for total tobacco production was 0.35, indicating that the data are normal, but the total ammonia air emissions p-value of < 0.05 denotes that the data are not normally distributed. Since one of the variables is not normal and the sample size is small, the Kendall rank correlation coefficient test is appropriate for identifying a relationship between the two variables (Puth et al., 2015).

4. Results

Figure 2 shows a comparison between the total weight of tobacco production and the total weight of ammonia air emissions in North Carolina. There is a noticeable decline in ammonia air emissions between 2010 and 2022. The production of tobacco peaked in 2014, steadily decreased until 2020, and slightly increased during and after 2021.

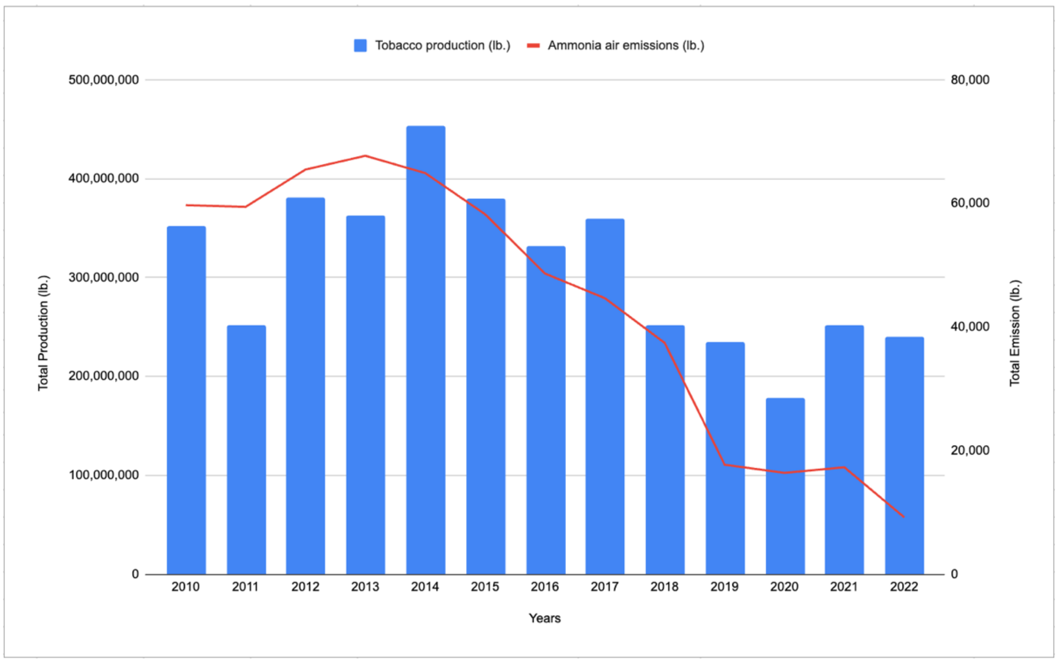

Figure 2. Total tobacco production (lb.) vs. total ammonia air emissions (lb.)

The Kendall rank correlation coefficient is used to assess the relationship between total production and total air emissions. The calculated Kendall tau (τ) value of 0.59 indicates a moderate positive correlation between total tobacco production and total ammonia air emissions. The $p < 0.05$ indicates that the relationship is statistically significant. Based on the calculations from Model 2, Figure 3 represents the ammonia air emissions per lb. of tobacco produced in North Carolina.

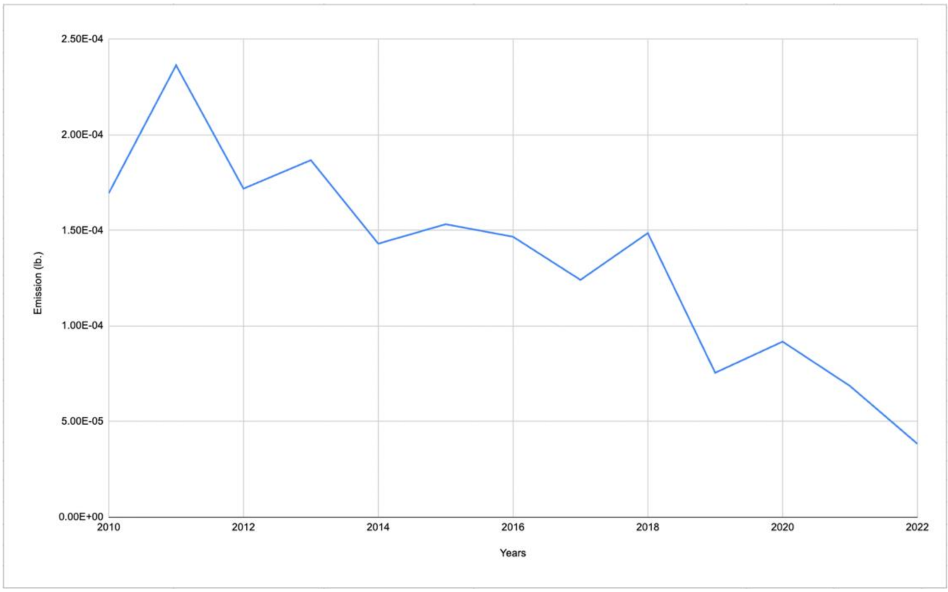

Figure 3. Ammonia emissions per lb. of tobacco production

The data show a noticeable fluctuation in emissions levels, peaking in 2011 with a decreasing downward trend over subsequent years until 2022. In particular, there are noticeable drops in 2014 and 2019. This downward trend suggests improvements in ammonia air emissions levels and a possible reduction of ammonia usage in the tobacco industry.

A regression analysis was conducted to find the *R*-squared value and the slope of the weighted emissions per lb. of tobacco production. These values explain the general trend of emissions per lb. of tobacco production over the period and explain the pattern by the passage of time (Priya Varshini et al., 2021).

The regression analysis value showed a negative slope of -1.26e-5, indicating that the North Carolina tobacco manufacturing industry is declining in lb. of emissions per lb. of tobacco. The R-squared value of 0.82 indicates that 82% of the variance in ammonia air emission levels can be explained by the passage of time, signifying a strong relationship between the variables. This suggests that the tobacco manufacturing industry has made progress in achieving lower ammonia air emissions levels during the production of tobacco and that improvements have been made to achieve these declining results.

5. Reactions and future studies

Based on these analyses, a moderate correlation between the total production and total air emissions suggests that the air emissions level is affected by the lb. of tobacco produced. It can be inferred from the overall trend of weighted emissions that North Carolina tobacco manufacturing facilities are improving in terms of their current ammonia emissions. A moderate correlation between production and total ammonia air emissions suggests that the total weight of tobacco produced affects emission levels.

Possible explanations for these reductions include the use of modular scrubbers and full-scale biofilters to reduce and remove ammonia and other contaminants in the tobacco industry (Woertz, 2002; Shareefdeen et al., 2005; Ralebitso-Senior et al., 2012; Kwiatkowski et al., 2019). In addition to biofilters, Wu et al. (2022) proposed that ammonia adsorption is a cheap and efficient method to reduce ammonia air emissions from steam during cigarette manufacturing, by capturing the ions using an adsorbent with a large surface area. The significant reduction in production levels might also explained by retaliatory Chinese tariffs on US agricultural products, as North Carolina lost around $81 million in tobacco exports as a result (Morgan et al., 2022). The number of facilities that reported to the TRI regarding ammonia emissions also declined, which may explain the sharp decrease in 2019 (see Table A1).

The results of this study highlight the levels of ammonia released from the North Carolina tobacco manufacturing industry. As mentioned previously, ammonia is a major culprit of $PM_{2.5}$ in the atmosphere, therefore, it is important to monitor the levels of these chemicals released into the air.

Although tobacco production and the number of smokers has been declining since 2015, it is important to understand mitigation strategies for a sustainable future. Future researchers should address whether the combustion and drying of tobacco leaves that are treated with ammonia result in air emissions or if ammonia is used separately and results in air emissions directly from the facilities. Moreover, as ammonia emission levels are decreasing, it is important to identify whether sustainable manufacturing processes are already being implemented throughout the facilities of North Carolina. While the use of cigarettes is known to cause severe health problems, cigarette butts require proper treatment during disposal as well because both incineration and disposal in landfills release hazardous fumes that pose risks to the environment and human health (Kurmus and Mohajerani, 2020). These results provide an opportunity for tobacco manufacturing stakeholders to apply sustainable procedures and transparency when reporting to external agencies (Jindrichovska et al., 2019).

The implications of decreased harmful ammonia emissions in recent years of tobacco production are important for the tobacco manufacturing industry and the entire agriculture industry, as reducing emissions can improve air quality and public health, especially for people who live or work near these facilities and for workers in these facilities. However, as tobacco products are already known to contain multiple carcinogens that cause cancer and severe cardiovascular diseases, the improvements made to reduce air emissions may not have a positive effect on these businesses (Hoffmann, 2017; Goel and Valerio, 2020). Even if these companies and their manufacturing facilities achieve full sustainability, they will inevitably face perceptions of 'greenwashing' in marketing and selling these products (Houghton et al., 2018).

Future researchers should investigate whether any significant regulatory milestones or technological process changes correlated with the 2011 spike in emissions. Similarly, future studies might explore if any similar instances correlated with the noticeable drops in 2014 and 2019. Future researchers might also analyze trends of other harmful carcinogens per pound of tobacco production. Were there any increases per pound of production? Do these decreased trends in tobacco production correlate directly with changes in air quality, secondhand smoke, or lung cancer in those regions? Future researchers should revisit the Meng et al. (2017) study noting the ammonia emissions in combustion and industrial processes to determine if other industries are also witnessing similar decreases in ammonia emissions as unveiled in this study.

Through a comprehensive analysis, this study ultimately found a 0.59 correlation between North Carolina tobacco production and ammonia air emissions. Policies and the adaptation of advanced technologies, such as ammonia adsorption or modular scrubbers are essential in mitigating the environmental impact of the tobacco industry concerning ammonia air emissions. Tobacco manufacturing facilities should adopt these technologies to further reduce ammonia air emissions, decreasing the chances of $PM_{2.5}$ formation in the air, and supporting the well-being of both the environment and society in the long term.

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Appendix

Table A1. Number of Facilities Reporting to TRI for Tobacco Manufacturing

Years	**Number of reporting facilities**
2010	8
2011	8
2012	8
2013	8
2014	8
2015	9
2016	8
2017	8
2018	8
2019	5
2020	5
2021	5
2022	4