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➢ ***ORAL PRESENTATION***

Investigation of the Risk of Delayed Action to Mitigation of Nitrous Oxide Emissions from Agricultural Systems

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Abstract

According to the United Nations Population Fund, the human population has grown from 1.6 billion to 6.1 billion people during the last century. As a conclusion, extensive consumption of fossil energy resources has associated with a significant increase in the mass of greenhouse gases. Nitrous oxide (N_2O) is one of the greenhouse gases with tremendous global warming potential and the creation of reactive nitrogen compounds has increased by 120%. Increasing greenhouse gas emissions and decreasing fossil fuel sources has been posed new challenges to agriculture. Because of the potential future effects of global climate change, people want to produce renewable fuel to reduce greenhouse gas emissions, but as the same time N_2O emission increase because of feedstock production and fertilizer production. Therefore, decision-makers need to develop the potential of mitigation strategies to quantify and address the uncertainty of N_2O emissions, so the correct strategies to mitigate N_2O emissions from agricultural systems can be found. According to policymakers, in a risk condition, each day of delay is associated with a risk of increasing greenhouse gas emissions instead of declining, so actions also need to be timely. The purpose of this study is to investigate of the risk of delayed action to mitigate N_2O emissions from agricultural systems. In this context, the consequences of inaction, risk analysis methods, N_2O mitigation technologies, cost associated mitigation strategies were analyzed and examined through the appropriate methods. According to results, the impact of one single year of delaying abatement would cause around 1.9 GtCO2e of additional emissions globally in that year. Also, the average effective lifetime of infrastructure is 10 years in the greenhouse gas cost curve model, so the model shows us a delay of 10 years would cut the potential abatement in 2030 would fall from 38 to 19 GtCO2e.

Keywords: greenhouse gases, nitrous oxide emissions, mitigation technologies, risk assessment, delayed action

INTRODUCTION

Approximately two billion people were added to the world's population over the past two decades (Rubino et al. 2019). As a result, extensive consumption of fossil energy resources, including coal, oil, gas, has associated with a significant increase in the mass of greenhouse gases (GHG) (carbon dioxide, nitrous oxide, water vapor, methane, ozone, etc.), which are known to inhibit long-wavelength radiation from escaping into space, into the atmosphere. Unfortunately, with the rapid increase in the population of humans since the mid-1970`s, the creation of reactive nitrogen compounds has increased by 120% (Galloway et al. 2008; Smithson 2002). Nitrous oxide (N_2O) is one of the GHG with tremendous global warming potential (GWP) (Wang and Sze 1980) because of its long atmospheric lifetime (approximately 120 years) and heat-trapping effects. The atmospheric concentration of N_2O varied only slightly thousands of years before the industrial period, but it started to increase relatively rapidly toward the end of the 20th century (CHANGE 2007; IPCC. 2007). Especially, the atmospheric concentration of N_2O has risen approximately 18% in the past two hundred years and continues to rise (Figure 1).

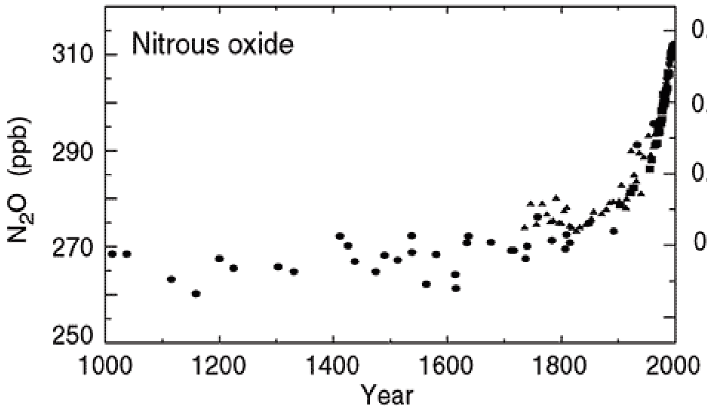
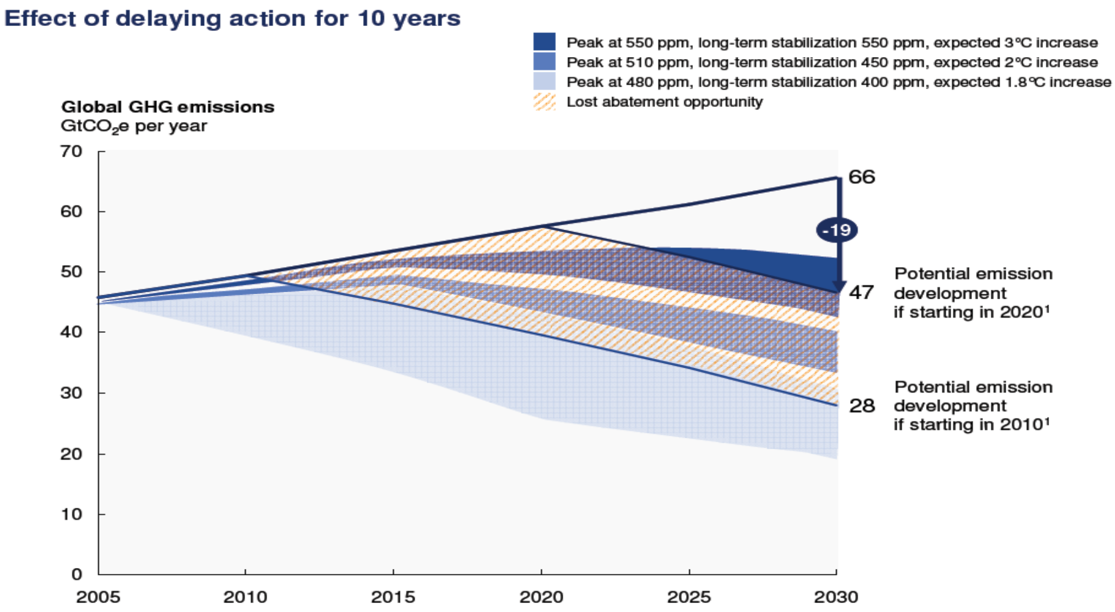


Figure 1. N_2O concentrations 1000 AD to 2000 AD (IPCC. 2007)

Based on the current U.S. GHG Inventory, N_2O contributes approximately 6.5% to total GHG emissions (in CO_2 equivalents) and N_2O emissions from agricultural soils account for more than 50% of the global anthropogenic N_2O flux (Hénault et al. 2019). Therefore, increasing GHG emissions and decreasing fossil fuel sources have been posed new challenges to agriculture (Fließbach et al. 2009). In this context, feedstock production for biofuels became a current issue worldwide. Nitrogen fertilization is increasing the amount of mineral nitrogen in soils and nitrous oxide emissions. Because the limiting factor for crop growth is the level of nitrogen availability, this is often a reason for lower crop yields in farming, but also a reason for lower emissions (Fließbach et al. 2009). On the other hand, using an extensive amount of nitrogen fertilizer to getting higher crop yields may lead to higher GHG emissions. Because of the potential future effects of global climate change, people want to produce renewable fuel to reduce GHG emissions, but at the same time, N_2O emissions increase because of feedstock production and fertilizer production. According to the low carbon fuel standard (LCFS), which seeks to reduce GHG emissions associated with fuel-powered vehicles considering the entire life cycle, in order to reduce the carbon footprint of fuels, this only occurs at the biorefinery, not feedstock production, N_2O estimations are too variable and uncertain. The key uncertainties in N_2O estimations are based on uncertainty in model input data and model structure (Del Grosso et al. 2010). Therefore, decision-makers need to develop the potential of mitigation strategies to quantify and address the uncertainty of N_2O emissions, so the correct strategies to mitigate N_2O emissions (e.g. using of nitrification inhibitors (such as 3,4-dimethylpyrazole phosphate (DMPP)); changing nitrogen source and application rate; fertilizer reduction; banded fertilization; wetland restoration and etc.) from agricultural systems can be found (Adler et al. 2012). When people are making decisions, they must determine not only which mitigation strategies to be chosen but also when they to be chosen. According to policy-makers, in a risk condition, each day of delay was associated with a risk of increasing GHG emissions instead of declining, so actions also need to be timely (Patalano and Wengrovitz 2007; McKinsey 2009). For example, if policymakers delay taking action, so global abatement action was to start 2020 instead of 2010, to keep global warming below 2 degrees Celsius would be nearly impossible according to Global Greenhouse Gas Abatement Cost Curve v 2.1. The impact of one single year of delaying abatement would cause around 1.9 GtCO2e of additional emissions globally in that year. Also, the average effective lifetime of infrastructure is 10 years in the greenhouse gas cost curve model, so the model shows us a delay of 10 years would cut the potential abatement in 2030 would fall from 38 to 19 GtCO2e (if the global abatement action starts in 2020 instead of 2010 (10 years of delaying), N_2O emissions will be 550 ppm instead of 480 ppm) (Enkvist, Dinkel, and Lin 2010; MacLeod et al. 2010; McKinsey 2009). As seen in Figure 2, the amount of reducing potential N_2O emission is also related to mitigation strategies. Therefore, appropriate N_2O emission mitigation strategies also should be examined since it is important as well as act now. In this context, the purpose of this study is to investigate the risk of delayed action to mitigate N_2O emissions from agricultural systems including the consequences of inaction, risk analysis method, and most used N_2O mitigation technologies analyzed and examined through the appropriate methods.



1 Technical levers < € 80/tCO_2e.
Source: Global GHG Abatement Cost Curve v2.0, v2.1; IEA; US EPA; Houghton; IPCC; OECD; den Elzen; Meinshausen; van Vuuren

Figure 2. Effect of delaying action and adopting more granular N_2O emission estimates and N_2O mitigation strategies compared with single N_2O emission factors (Smithson 2002; McKinsey 2009)

The Risk Assessment Framework

In a simple definition, the risk is an inherent property of everyday human existence, so a key factor in all decision making. Risk assessment can be defined as the process of estimating both the probability that an event will occur, and the probable magnitude of its adverse effects such as economic, health-related, or ecological from a chemical or stressors over a specified time period (Gerba 2006; Olson and Gurian 2012). A formal risk assessment has four steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization as shown in Figure 3.

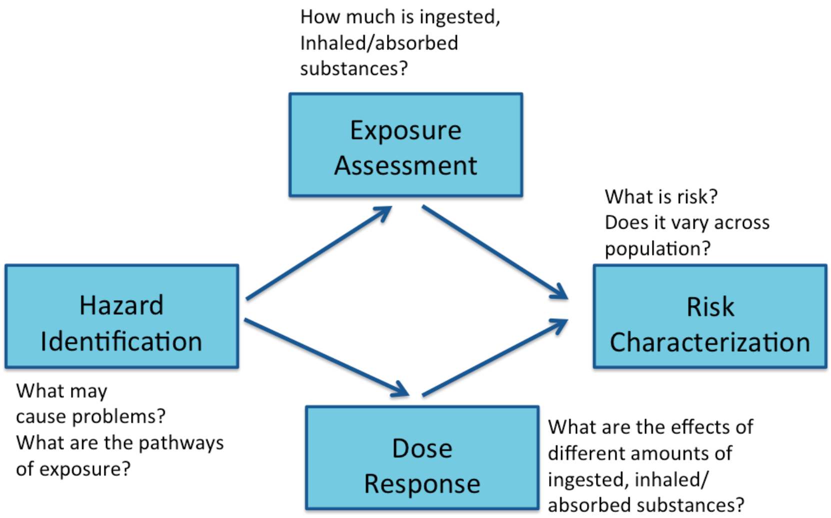


Figure 3. Risk assessment framework (Gerba 2006)

The Process of Risk Assessment

1- Hazard identification: Definition of the hazard is the potential for harm or an adverse effect on humans; for example, identifying chemical contaminants such as, a heavy metal, and documenting its toxic effects on humans. For N_2O, the substance can be absorbed through the skin as well as inhaled. Elevated concentration of N_2O in the air will be reached very quickly on loss of containment such as, with leaking.

2- Exposure assessment: Calculation exposure requires information on the concentrations of contaminants and the timeframe over which exposure occurs in target organisms. For example, finding the concentration of mercury in canned tuna products and determining the dose an "average" person would receive. For inhalation of N_2O, the reported intake/contact rate (IR) is 20 m^3/day; exposure frequency (EF) is 350 days/year; exposure duration (ED) is 30 years (EPA 1991).

3- Dose-response assessment: Quantifying the adverse effects arising from exposure to a hazard on the degree of exposure. For average daily dose (or chronic daily intake) of N_2O is normalized as milligrams of N_2O inhaled through the skin per kilogram of body weight per day (mg kg^{-1} day^{-1}).

$$\mathrm{CDI} = \frac{\mathrm{C \ x \ IR \ x \ EF \ x \ ED}}{\mathrm{BW \ x \ AT}} \qquad (1)$$

where CDI is chronic daily intake; C is concentration of chemical in each medium (e.g., mg/L for water or mg/m^3 for air); IR is intake/contact rate (L/day); EF is exposure frequency (days/year); ED is exposure duration (years); BW is body weight (kg); AT is averaging time (period over which the exposure is averaged-days). According to United States Environmental Protection Agency (EPA 1991), standard default exposure factors for inhalation of contaminants: IR is 20 m^3/day; EF is 350 days/year; ED is 30 years; BW is 70 kg; AT is 24500 days (350 days/year x 70 years). If global abatement action starts 2010, N_2O emissions will be 480 ppm. Therefore, chronic daily intake will be 587 mg $kg^{-1}day^{-1}$. However, if global abatement action starts 2020 instead of 2010 (10 years of delaying), N_2O emissions will be 550 ppm. Therefore, chronic daily intake will be 670 mg $kg^{-1}day^{-1}$.

4- Risk characterization: The process of determining the potential impact of a hazard based on the severity of its adverse effects and the amount of exposure (Gerba 2006). The Office of Environmental Health Hazard Assessment (OEHHA) of the California Environmental Protection Agency added N_2O to the list of chemicals known to the state to cause cancer and reproductive toxicity for the purposes of Proposition 65. Previous studies on the adverse effect of N_2O have mostly focused on air pollution and risk for lung cancer (Raaschou-Nielsen et al. 2011; Pope Iii et al. 2002). However, other cancer types might also be associated with exposure to polluted air with high level of N_2O concentrations such as cancers of the mouth, pharynx, and larynx. Although further studies are required to confirm possible risks for other cancers, the study of Raaschou-Nielsen, Andersen and et al. 2011 showed that the risk for kidney cancer increased with increased N_2O concentration near the residence. Also, the substance may have effects on the bone marrow and the peripheral nervous system. High N_2O concentration may cause reproductive toxicity in humans. Beside the direct human health effects of N_2O, another concern is related to environment. When N_2O emissions reaches the stratosphere it destroy the ozone layer, as a result UV radiation level increased (Portmann, Daniel, and Ravishankara 2012). Air quality guidelines such as those from the World Health Organization (WHO), the United States Environmental Protection Agency (EPA) and the European Union (EN) are based on detailed studies designed to identify the levels that can cause measurable health effects. According to the scientists, breathing ground-level ozone can result in a number of adverse health effects including respiratory symptoms such as coughing, wheezing, throat irritation, and increasing the risk of skin cancer, lung cancer and also generally all types of cancer since when N_2O is nearer to the Earth's surface cause smog which has been linked to weakening of the immune system. As a summary, N_2O emissions may not have direct cancer effect. However, ozone depletion also should be considered if thinking about its important side effects.

N_2O gas Mitigation in Agriculture

According to the scientists, 37% of the earth's land surface was occupied by agricultural lands and agricultural activities are responsible 52% of global methane and 84% of N_2O emissions (Smith and Conen 2004). Agriculture releases significant amount of atmospheric N_2O which is generated by the microbial transformation of nitrogen in soils, and is often enhanced where available nitrogen exceeds plant requirements (Smith and Conen 2004; Cole et al. 1997; Paustian et al. 2004). Adler, Del Grosso et al. are reported that the major GHG contributors in the life cycle of a biofuel product are nitrogen fertilizer useage; N_2O emissions; harvesting (Adler et al. 2012). Their total contribution from N fertilizer useage and N_2O emissions accounted for 42-80% of the GWI (Global Warming Intensity) for feedstock production. Agricultural GHG emissions are complex, however the management of agricultural systems offers possibilities for mitigating GHGs in agriculture including reducing emissions; enhancing removals; avoiding emissions. Cropland management is the one of the significant mitigation technologies since it focusses on agronomy, which aims to increase crop yields and reduce emissions (Follett 2001; Paustian et al. 2004); nutrient managements, which aims to apply nitrogen more precisely into the soil (Cole et al. 1997; Paustian et al. 2004; Monteny, Bannink, and Chadwick 2006); tillage management, which effects N_2O emissions directly since reducing soil tillage may promote atmospheric N_2O (Marland, McCarl, and Schneider 2001; Rauch et al. 2009); water management, which can reduce N_2O emissions promoting productivity (Monteny, Bannink, and Chadwick 2006); and land cover change since grassland can reduce N_2O emissions. In addition, management of land, organic soils, and manure can also reduce N_2O emissions if they are applied properly (Follett 2001). Efficient mitigation strategies should aim to provide enough nitrogen to satisfy plant demand, while minimizing excess nitrogen. Several challenges should be examined when considering about the most-effective GHG mitigation options including emissions which are under BAU conditions; the impacts of GHG mitigation strategies on crop yields and environmental impacts; interactions between different GHG technologies; and cost and benefit analysis for different mitigation options. There are two important N_2O mitigation strategies reported to reduce the GWI of bionergy feedstock production (based on corn grain) among all mitigation technologies, which are PCU (Polymer-coated urea) and nitrification inhibitors. Nitrogen source, application rate, application time, and placement are the key factors to reducing nitrogen inputs. Among them, nitrogen source and application rate are the most approprite methods for reducing embodied energy and N_2O emissions. This process is worked by gradual diffusion of nitrogen through the polymer coating dependant on soil moisture and temperature. It is required less energ so slow release rate of N is more precise than most slow-release products. In addition, release depends on coat thickness, chemistry, temperature, moisture. Although polymer-coated fertilizers have several advantages including high quality and consistent analysis, an elimination of a fertilizer impregnation stage, utility in cost-share programs, and decreased need, time and effort, it is often more expensive method than other forms of nitrogen. On the other hand, nitrification inhibitors, such as dicyandiamide and 2-ethynylpyridine, are applied to agricultural soil with nitrogen fertilizers to reduce nitrate leaching and N_2O emissions, and as result increase plant growth. However, the effectiveness of them decreases time after application to soils depending on soil temperature, soil moisture, soil pH and organic matter content(Edmeades 2003). Adler, Del Grosso et al. compared two of N_2O mitigation strategies to reduce the GWI of bioenergy feedstock production, based on corn grain (Adler et al. 2012). When PCU uses as a mitigation strategie, N_2O emissions reduce %14-58. On the other hand, if the nitrification inhibitor uses as a mitigation strategie, N_2O emissions reduce %31-44. This high range of percentages difference shows us N_2O emissions reductions in a mitigation strategie depends on many factors.

CONCLUSION

The study investigated the risk of delayed action to mitigate N_2O emissions from agricultural systems. The importance of N_2O emissions, consequences of inaction, risk assessment analysis for N_2O emissions, N_2O mitigation technologies have been studied. The average effective lifetime of infrastructure is 10 years in the greenhouse gas cost curve model shows us a delay of 10 years would cut the potential abatement in 2030 would fall from 38 to 19 GtCO2e. In this case, N_2O emissions will be 550 ppm instead of 480 ppm. Using this data, we processed a risk assessment analysis and found that if global abatement action starts 10 years of delay, the chronic daily intake will be 587 mg $kg^{-1}day^{-1}$ instead of 670 mg $kg^{-1}day^{-1}$. Due to the increased atmospheric N_2O emissions, several human health and environmental effects were summarized. Since the major N_2O emission is related to agricultural activities, several N_2O mitigation technologies were investigated and among them, polymer-coated urea and nitrification inhibitors were reported as two important N_2O mitigation strategies to reduce the global warming intensity. In summary, this study can provide awareness and knowledge to both policymakers and engineers on how to reduce N_2O emissions and decrease adverse effects on humans and the environment.

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