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Emissions Associated with Animal Agriculture and Mitigation Opportunities within the Industry

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Abstract

As the livestock industry contributes 7.1 gigatonnes of CO_2 eq. annually to anthropogenic emissions, and the industry is expected to grow approximately 70% by 2050, it is imperative that mitigation opportunities are explored to decrease emissions from the industry. In this paper, a meta-analysis of four mitigation opportunities were analyzed that would target the four stages of the livestock lifecycle analysis- feed production, enteric fermentation, manure management, and energy consumption. The first strategy explored was to increase soil vegetation time through the use of fertilizers and agroecological methods to increase the soil used for feed production's ability to sequester CO_2. The second strategy explored was implementing small and large scale methane digesters to farms globally to sequester methane emitted by ruminant species and use this methane as a fuel source for other industry activities. The next strategy was improving animal feed and genetics through the use of chemicals and pharmaceuticals to the feed and to the animals to decrease the amount of methane the animals produced during enteric fermentation. The last strategy was to convert all fossil fuel energy requiring processes within the lifecycle to renewable sources of energy to omit the necessity for fossil fuels in energy consumption processes within the industry. It was found that the cumulative effect of the implementation of all strategies would result in a 3.235 gigatonnes of CO_2 eq., or 45.564% reduction of greenhouse gasses from the livestock industry globally. This was modeled through the use of stabilization wedges to visualize the effect of these mitigation strategies.

Introduction and Justification

The livestock industry accounts for 14.5% of total anthropogenic carbon dioxide emissions and our consumption of animal products is expected to increase approximately 70% by 2050 (Gerber et Al., 2013). It is more important now than it ever has been to explore mitigation options for emissions associated with the animal agriculture industry as our global warming trajectory is rapidly increasing and so is our consumption of animal products. The predominant greenhouse gases emitted from the animal agriculture industry include carbon dioxide, methane, and nitrous oxide, with methane and nitrous oxide having significantly higher global warming potentials than carbon dioxide. Since our consumption of animal products is expected to increase significantly by midcentury, it is of the utmost importance that we seek ways to decrease emissions from the industry by either decreasing or discontinuing our production of animal products, or developing innovative technological or policy-based solutions to mitigate the emissions associated with the industry.

In this paper, four technical mitigation strategies will be analyzed to determine the potential reduction of greenhouse gasses associated with the production of livestock if these mitigation strategies are applied globally. The mitigation strategies chosen target the emissions associated with the four processes of the livestock lifecycle analysis- feed production, manure management, enteric fermentation, and energy consumption. Socolow's concept of stabilization wedges will be used to help visualize the impact of applying the technical mitigation strategies on our global warming trajectory. Analyzing the mitigation potential of greenhouse gases associated with the production of livestock will help us understand if technical mitigation strategies are enough to significantly reduce emissions associated with livestock, or if further policy or education based solutions need to be explored in addition to or as alternatives to technical mitigation strategies alone.

Literature Review

In this literature review, statistics regarding the emissions associated with the livestock industry will be analyzed with a focus on what the effect of discontinuing our consumption of animal products entirely would be on environmental health. Alternative strategies to simply discontinuing our consumption will also be discussed including improvements in - feed production, manure management, enteric fermentation, and energy consumption.

- Greenhouse gas emissions associated with various stages of the animal agriculture industry

Emissions associated with the animal agriculture industry are primarily comprised of methane, carbon dioxide, and nitrous oxide, which occur in different amounts at various stages of the production process. In Bristow's "Global climate change and the industrial animal agriculture link: The construction of risk", the author discussed several studies regarding the emissions associated with all stages of the production process of animal products including "Livestock's Long Shadow, a report by the United Nation's Food and Agriculture Organization, which indicated that the industrial animal agriculture sector as a whole contributes more to global climate change than the transportation sector" (Bristow, 2011). The findings in this report were very significant because it proved that by using a lifecycle analysis of animal products, we learn the immense cumulative impacts of the production and distribution of animal products. This finding is also supported by the 2013 report by the UN Food and Agriculture Organization that found that the production of livestock "represent 14.5 percent of all human-induced emissions" which are estimated at 7.1 gigatonnes of CO2 equivalent from the entire livestock supply chain (FAO, 2013).

In Koneswaran and Nierenberg's "Global farm animal production and global warming: impacting and mitigating climate change", the authors provided more information about the resources and emissions from the entire supply chain of animal products by conducting "an analysis of meat, egg, and milk production encompasses not only the direct rearing and slaughtering of animals, but also grain and fertilizer production for animal feed, waste storage and disposal, water use, and energy expenditures on farms and in transporting feed and finished animal products, among other key impacts of the production process as a whole" (Koneswaran, G., & Nierenberg, D, 2008). Their discussion provides insight into the emissions associated with all stages of the production process of animal products. This is important to our understanding of the cumulative impact of producing animal products because the article discusses the lifecycle analysis of animal products, meaning the emissions associated with every stage of the production process from producing feed for the animals to distributing the final product. The article focused primarily on nitrous oxide and methane emissions as their global warming potential are much higher than carbon dioxide (methane has a GWP of 23, and nitrous oxide has a GWP of 296). They found that the animal agriculture industry alone is responsible for 18% of anthropogenic emissions, but it is responsible for 35-40% of the annual anthropogenic methane emissions and 65% of global nitrous oxide emissions. The article also listed some interesting statistics about the emissions associated with various stages of the production process including that burning fossil fuels to produce fertilizers for feed crops may emit 41 million metric tons of CO_2 per year and an additional 90 million metric tons of CO_2 per year may be emitted by fossil fuels expended for intensive confinement operations. It also stated that animal product production also results in releases of up to 28 million metric tons of CO_2/year from cultivated soils.

In a 2020 report produced by the FAO, it was found that cattle produce the vast majority (62%) of emissions associated with producing livestock. Of these emissions the majorty are methane, which has a significantly higher global warming potential that carbon dioxide, making emissions associated with producing cattle significantly greater than other species. Therefor, there will be more mitigation strategies aimed at mitigating methane emissions associated with producing cattle.

- How much greenhouse gas emissions would decrease if we discontinued our consumption of animal products

To understand the full extent that producing animal products has on environmental health, we can look at statistics of what it would look like if we discontinued our production of animal products entirely would be on cumulative emissions to understand the vast contribution that the agriculture industry has on total global emissions. Rosi, Pellegrini, Turroni, Neviani, Ferrocino, and Scazzina's

2017 article “Environmental impact of omnivorous, ovo-lacto-vegetarian, and vegan diet” offers an important explanation of the difference in emissions and environmental impacts between three common diets. In the study, 153 adults (51 omnivores, 51 ovo-lacto-vegetarians, 51 vegans) were monitored through the use of a dietary record to determine the environmental impact of each diet. The study found that “the omnivorous choice generated worse carbon, water and ecological footprints than other diets” and “no differences were found for the environmental impacts of ovo-lacto-vegetarians and vegans” (Rosi et al., 2017). In agreement with Rose et al.’s 2017 article which explained that a diet lower in animal products produced fewer environmental impacts than a diet high in animal products, an article published on Climate Nexus stated, “Consumption of meat and dairy products are expected to rise 76 and 64 percent respectively” by 2050, so it is absolutely imperative that we begin decreasing our animal products soon so that emissions do not continue to rise with the rise in consumption of animal products (Climate Nexus). The article then explains the carbon dioxide intensity that occurs from raising cattle by explaining that “beef consumption creates 1,984 pounds of CO2 annually” and “replacing beef with plants would reduce that figure 96 percent, bringing it down to just 73 pounds of CO2” (Climate Nexus). This describes the enormous potential that decreasing our production and consumption of animal products could have on environmental health due to the massive decrease in emissions.

- Mitigation strategies

Since it is not entirely reasonable to expect our production and consumption of animal products to entirely discontinue in the near future, we must look at technical strategies for mitigation of emissions within the industry. In Mosier, Duxbury, Freney's "Climate Change", the authors discuss three mitigation strategies that could be used to decrease emissions from the animal agriculture industry. The three strategies include reducing emissions, enhancing removals, and avoiding or displacing emissions. To reduce emissions, the article states "fluxes of these gases can be reduced by managing more efficiently the flows of carbon and nitrogen in agricultural ecosystems. For example, practices that deliver added N more efficiently to crops often suppress the emission of N_2O and managing livestock to make most efficient use of feeds often suppresses the amount of CH_4 produced", meaning that the strategy used to mitigate emissions should be to control fertilizers used on the crops fed to livestock in order to ensure efficiency in CAFOs (Mosier, Duxbury, Freney's, 2007). Under the enhancing removals strategy, the article explains that we should increase our ability to sequester carbon through implementing various technologies and natural carbon sinks that would work to remove atmospheric CO2. In order to remove or displace emissions, the article suggests that "crops and residues from agricultural lands can be used as a source of fuel, either directly or after conversion to fuels such as ethanol or diesel", meaning that byproducts of the animal product production process should be used to fuel the transportation of the products to retailers (Mosier, Duxbury, Freney, 2007).

The 1997 article “Soil Use and Management” written by Paustian et. Al discusses a multitude of techniques that can be applied to various agricultural regions globally in order to improve soil’s ability to sequester carbon. This study was highly inclusive because it surveyed every country/climate region that produces agricultural commodities in order to make productive suggestions about how that region can improve their soil’s ability to sequester carbon and not further deplete the soil of its nutrients. This is important because different weather or socio-economic conditions in various regions affect that region’s farms ability to implement certain mitigation strategies, so a more targeted approach was used. Some of the mitigation strategies include increasing soil vegetation time, reducing or eliminating soil tillage, increasing use of perennial grasses and legumes as forage crops, increasing cover crops, and applying green manures. It was found that .59 gigatonnes of carbon dioxide could be sequestered if these mitigation strategies were implemented.

In Hedenus, Wirsenius, and Johansson’s 2015 article “The importance of reduced meat and dairy consumption for meeting stringent climate change targets”, the article also describes three strategies to decrease emissions from agriculture, similar to Mosier, Duxbury, and Freney’s 2007 article: 1) productivity improvements, particularly in the livestock sector; 2) dedicated technical mitigation measures; and 3) human dietary changes. The goal for the mitigation strategies discussed in this paper is mitigate emissions within the livestock industry to remain under the 2 degree Celcius target for global warming. The analyses of the three strategies indicate “if structural changes in human diets are included, emissions may be reduced further, to 3–5 Gton CO_2eq/year in 2070. The total annual emissions for meeting the 2 °C target with a chance above 50 % is in the order of 13 Gton CO_2eq/year or less in 2070, for all sectors combined. We conclude that reduced ruminant meat and dairy consumption will be indispensable for reaching the 2 °C target with a high probability, unless unprecedented advances in technology take place" (Hedenus, Wirsenius, and Johansson, 2014). The evaluation of these strategies are important because they give insight to the exact quantity of emissions that we must stay beneath in order to maintain our goal of not surpassing a 2 degree Celcius increase in global temperature.

As technological options are improving for sequestering emissions, it is important that we explore the option of implementing technology-based solutions for emissions associated with agriculture. One of the technological options for decreasing emissions from agriculture is discussed in the article published on Animal Feed Science and Technology in 2019, "Effect of the volume of methane released into respiration chambers on full system methane recovery", which describes a device that uses an infrared methane analyzer to decrease the volume of methane released into a chamber. The study found that found that "as the volume of methane released into the respiration chambers was decreased, methane recovery percentages were concomitantly reduced. The recovery percentages ranged from 103.7% down to 18.3% and from 102.7% down to 31.6% for chambers one and two, respectively" (Castillo, et al 2019). If this technology is applied to the agriculture industry, we could see a massive decrease in emissions since the global warming potential for methane is significantly higher than carbon dioxide.

In the 2015 Chatham House Report “Changing climate, changing diets: Pathways to lower meat consumption”, the article discusses another important strategy for decreasing emissions associated with animal agriculture and that is to educate the public on the harmful effects of the livestock industry and what they can do as consumers to decrease their carbon footprint. In the article, the authors explain that “governments are the only actors with the necessary resources and capacities to redirect diets at scale towards more sustainable, plant-based sources of protein”, meaning that we must change policies to push educating the public in order to decrease our intake of animal products which would decrease the demand for production and thus decrease the emissions associated with the agriculture industry because governments and a change in policy has the most influence on individuals (Wellesley, Froggatt , and Happer, 2015).

The use of modeling can be very important when determining mitigation strategies to reduce emissions associated with the production of animal products. McAllister, Beauchemin, McGinn, Hao, and Robinson’s 2011 article “Greenhouse gases in animal agriculture—Finding a balance between food production and emissions” describes the “importance of modeling GHG from an agricultural systems perspective was apparent, both in a policy making and regulatory perspective” to explain why we must “mitigate enteric CH_4 emissions from ruminants, as well as CH_4 and N_2O emissions from manure” (McAllister, Beauchemin, McGinn, Hao, and

Robinson, 2011). An important model for depicting the importance of mitigating the environmental impacts of the animal agriculture industry is Cleveland's model of "the zone", which describes "the zone where human impact approaches human carrying capacity" (Cleveland, 29). This is an important model for the justification of mitigating emissions from the animal agriculture industry because it shows that human demand on the planet is exceeding our planet's ability to provide resources for us. This model ties into Socolow's stabilization wedges because it can show how much we could decrease our trajectory towards exceeding our carrying capacity if we accomplish one of Socolow's wedges of cutting emissions from agriculture through the mitigation strategies discussed. Socolow's stabilization wedges are "a portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO2 to a trajectory that avoids a doubling of the preindustrial concentration", which could help us deviate away from Cleveland's "zone", in which there will be environmental catastrophe (Socolow, 2004). By achieving Socolow's one of Socolow's wedges, which include mitigating emissions from agriculture, we can use Cleveland's model of the zone to understand the impact that production of animal products has on the carrying capacity of our planet.

Research Question

The main argument that I am trying to prove in my paper is that the production of livestock is detrimental to environmental health, but applying technical mitigation strategies to the livestock industry may help decrease the emissions associated with the livestock industry. My main research question is: How much would our total emissions decrease if we applied technical mitigation strategies to the four processes in the livestock lifecycle analysis? The goal of my project is to provide a discussion of the research about the emissions associated producing livestock and how much these emissions could be decreased if we applied technical mitigation strategies or discontinued producing these products entirely. Since it is not entirely realistic to expect the industry to discontinue production entirely, I will conclude my research by suggesting some policy or education-based options for decrease emissions from producing livestock.

Methods

To answer my main research question, I will answer the following questions, which lead up to the main research question (in bold).

- What are our current GHG emission associated with all stages of animal product production?
- What would GHG emissions look like if we all discontinued our consumption of animal products entirely?
- What are some technical ways of mitigating emissions within the animal agriculture industry?
- How much would our global warming trajectory decrease if we applied the technical mitigation strategies analyzed (Socolow's concept of stabilization wedges will be used to help visualize)

- **How much would our total emissions decrease if we applied technical mitigation strategies to the four processes in the livestock lifecycle analysis?**

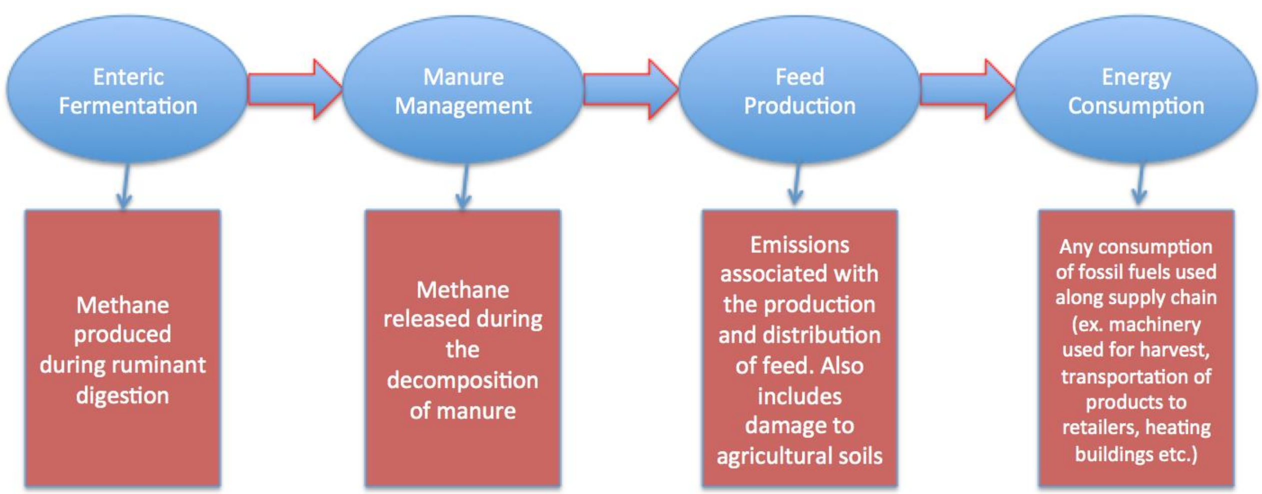
The answers to these questions will be supported by data found from academic sources. I also plan on using modeling (Socolow's stabilization wedges to depict how much decreasing emissions from agriculture could decrease our global warming trajectory). The primary method used to write this paper is a meta-study, meaning that I will combine the results from multiple studies in order to answer my own research question. A meta-study is the most optimal way to conduct this analysis because technical mitigation strategies have already been written about in great detail by various authors and their emission reduction potentials have already been determined. I plan on analyzing the literature to determine the best mitigation strategies to decrease emissions from four sectors of the livestock lifecycle and quantify their cumulative reduction potential to answer my own research question.

I will analyze four mitigation strategies that target each process in the lifecycle analysis and determine how much each mitigation strategy could decrease total emissions from the livestock industry. These numeric values will be converted into gigatonnes of CO_2 eq. in order to standardize the results and determine the total percent decrease these mitigation strategies have the potential to produce. A stabilization wedge will then be created to help visualize the significance of the mitigation strategies. Stabilization wedges are a concept created by Stephen Pacala and Robert Socolow that combine various technical strategies that already exist today that will help reduce greenhouse gas emissions globally. Every time a "wedge", or mitigation strategy, is accomplished, our global warming trajectory decreases in varying amounts depending on the strategy's reduction potential. Stabilization wedges are a good way to depict the results found from this meta-study because they primarily analyze technical strategies for mitigation and give a clear visual representation of the effect of certain mitigation strategies on total emissions from an industry. My stabilization wedge will be focused on the animal agriculture industry and will be comprised of the four technical mitigation strategies analyzed. Finally, the results from my study will be analyzed and a determination will be made regarding if technical mitigation strategies are enough to significantly reduce emissions associated with producing livestock.

Results

A lifecycle analysis was used to identify strategies to reduce emissions in all sections of the lifecycle analysis for the production of livestock.

The lifecycle analysis for the livestock industry:



The boxes in red describe the focus of mitigation efforts for the corresponding sections of the lifecycle analysis.

Results table:

Section of LCA that Reduction Strategy will Target	GHG Reduction Potential (Gigatonne CO_2 Eq.)	Degree of Uncertainty	Reduction Strategy	Citation
Feed Production	.59	High	Increase soil vegetation time; Reduce or eliminate soil tillage; Increase use of perennial grasses and legumes, as forage crops; Increase cover crops; Apply green manures	Paustian, K., Andrén, O., Janzen, H., Lal, R., Smith, P., Tian, G., … Woomer, P. (1997). Agricultural soils as a sink to mitigate CO 2 emissions. *Soil Use and Management*, *13*, 230–244. https://doi.org/10.1111/j.1475-2743.1997.tb00594.x
Manure Management	.16	Low	Applying the use of small and large scale methane digesters to farms globally	Mosier, A., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., & Johnson, D. (1998). Mitigating Agricultural Emissions of Methane. *Climatic Change*, *40*(1), 39–80. https://doi.org/10.1023/A:1005338731269

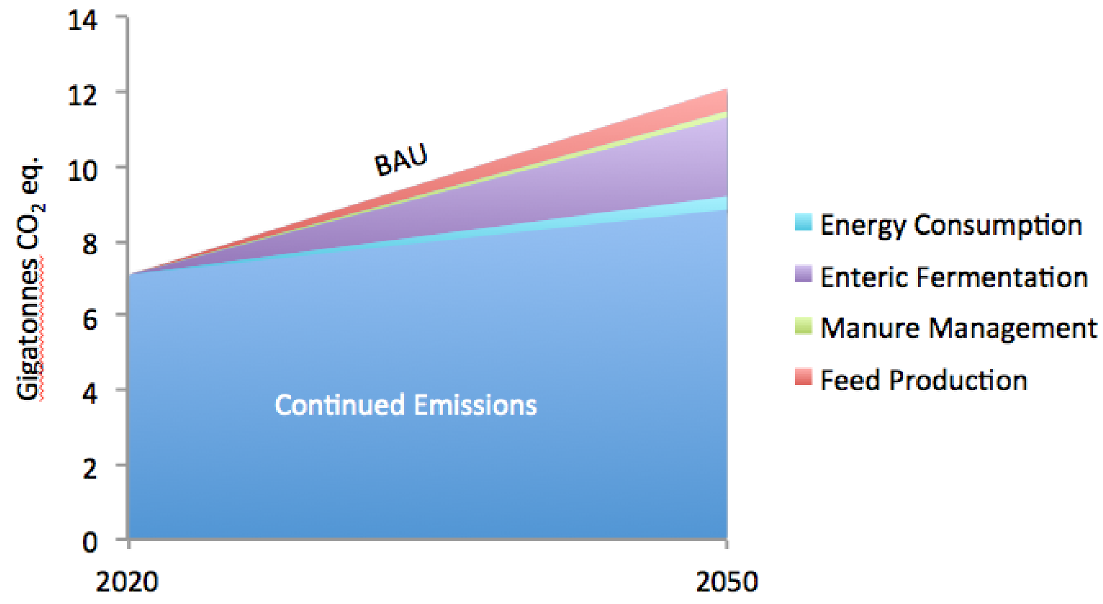
Enteric Fermentation	2.13	Medium	Improve animal feed, improve animal genetics, apply pharmaceuticals to decrease methane emissions primarily from ruminant species	Mosier, A., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., & Johnson, D. (1998). Mitigating Agricultural Emissions of Methane. *Climatic Change*, *40*(1), 39–80. https://doi.org/10.1023/A:1005338731269
Energy Consumption	.355	Low	Covert all processes within the production of livestock that require fossil fuels to renewable sources of energy.	Figures used: GLEAM 2.0 - Assessment of greenhouse gas emissions and mitigation potential. (n.d.). Retrieved February 2020, from http://www.fao.org/gleam/results/en/

Total:

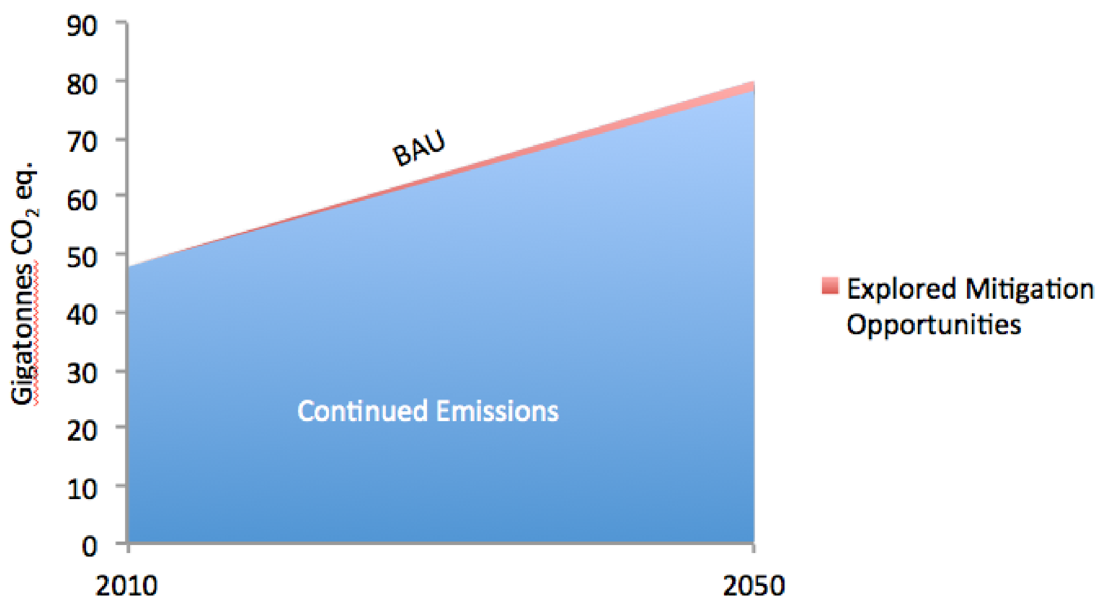
- 3.235 gigatonnes of CO_2 eq. can be reduced
- 45.564% reduction of greenhouse gases from the livestock industry
- 2.278% of global emissions could be reduced if these technical mitigation strategies were applied to the livestock industry

Stabilization Wedges

Wedge showing reduction in emissions from livestock industry from explored mitigation opportunities:



Wedge showing reduction in emissions from overall global emissions from explored mitigation opportunities:



The 1997 article "Soil Use and Management" written by Paustian et. al. was used as a source for the chosen mitigation strategy for feed production because it was widely cited by over 500 people and gave extensive information about various factors that impact soil's ability to sequester carbon. The methodology used to compose this report was a compilation of various case studies from every global region (characterized by both country and climate) that fosters agriculture including North America, Europe, tropical regions, Asian countries, semi-arid regions etc. The extensive amount of regions surveyed in this study allows for a more productive implementation of various soil-carbon sequestration improvement techniques depending on the local climate, making this a very inclusive and reliable source.

The 1998 article "Mitigating Agricultural Emissions of Methane" written by Mosier et. Al. was chosen because of the in depth information about various mitigation techniques for agricultural emissions of methane, specifically from ruminant species. The authors gave multiple technical opportunities for manure management and enteric fermentation mitigation techniques as well as the technical strategy's projected mitigation potential, which was imperative for the composition of the results for this study. Additionally, the research question posed in this article closely matched the research question of this study. The methodology used to write this study was a meta-study, which compiled results from case studies and statistics from over 110 peer-reviewed sources, making the results from this study highly inclusive of many academic sources. This is very beneficial because it reduces the chance that important mitigation strategies were missed during the research for the composition of this paper.

Discussion

There are several degrees of uncertainty and other problems associated with the results presented in this meta-study. First, meta-studies are not always the most accurate or reliable studies because they fail to analyze every possible mitigation strategy from the literature. This is because it is impossible to read all peer-reviewed sources to determine which mitigation strategies offer the greatest greenhouse gas reduction potential, therefor it is likely that one or more important studies and their strategies were not analyzed. Additionally, meta-studies frequently tend to be dominated by one single study. This is something that was encountered during the production of this study because the 1998 Mosier et. Al. study provided many crucial mitigation strategies and statistics used in this paper. This may have occurred because my personal research question and the research question posed by Mosier et. Al. were similar.

Another problem associated with this study was the use of stabilization wedges. Although stabilization wedges are a very effective way at visualizing the reduction potentials of primarily technical solutions, they fail to take into account economic, social, and cultural limitations of certain strategies. For example, for the entire 3.235 gigatonnes of CO_2 eq. to be reduced from producing livestock, these mitigation strategies must be applied globally. In third world countries, gathering the capital and infrastructure required to switch entirely to renewables, purchase methane digesters, various pharmaceuticals, and fertilizers required for these mitigation strategies is not feasible.

Another important note regarding the accuracy of the stabilization wedges is that there is no explicit dates set in all four articles of literature explaining the mitigation opportunities explored. This means that there is uncertainty regarding how long it would take for the quantities of emissions to be sequestered by the mitigation strategy, making the projections for mitigation illustrated by the stabilization wedges uncertain. The projections were set to mitigate the emissions by approximately midcentury for most strategies, but this does not take into account the duration it would take to establish these various solutions or how long it would take to actually sequester the carbon dioxide and methane emissions from the industry.

There are also some degrees of uncertainty associated with the actual mitigation strategies themselves. The degrees of uncertainty were determined based on the quantity of disclaimers present in the scholarly literature regarding the reliability of the results. The technical mitigation strategy for soil management in Mosier et. Al. explained that there is a high degree of uncertainty for the mitigation potential of these strategies because it is "unclear whether erosion, at the regional level, increases or decreases C stocks in soils and sediments" and therefor the article neglects to include the effects of erosion on soils ability to sequester carbon. Additionally, the authors state that "the decomposability of soil organic matter varies along a continuous gradient and there is no biological process which renders organic C completely inert. Thus, any definition of sequestered C based on a particular residence time would be purely arbitrary", meaning that not all soil possesses the same ability to sequester carbon so the exact sequestration potential for agricultural soils can only be estimated.

For the technical solution for enteric fermentation a mechanistic digestion model for cows was used which is a good predictor of methane emissions was used. However, there is insufficient data in current literature to describe the distribution of animal's age or descriptors to help characterize the quantity and quality of their feeds. Part of this mitigation strategy also included a case study from China where the treatment of straw with NH_3 fed to cows was attempted, but it was found very difficult to actually implement, making the feasibility of implementing this mitigation strategy questionable.

Conclusion and Recommendations

It was found that if the technical mitigation strategies analyzed (improving feed production, manure management, and decreasing enteric fermentation and energy consumption) were applied to the livestock industry, the cumulative effect of all four strategies would result in a 3.235 gigatonne CO_2 eq. reduction, or a 45.564% reduction of greenhouse gases associated with the livestock industry.

While the reduction strategies analyzed have a significant potential to decrease emissions from the livestock industry, the animal agriculture industry only accounts for 5% of total global emissions. This means that if these mitigation strategies were applied, only 2.278% of global emissions could be reduced by these technical mitigation strategies for the livestock industry. Since this is a very small reduction in overall emissions, it is clear that in order to decrease our emissions from the agriculture industry significantly, we need to decrease our consumption of animal products.

If everyone globally ate two-thirds of their meals completely vegan, meaning that there would be no consumption of animal products or byproducts in the meal, their individual food-related emissions would decrease by 60%. This would mean that there would be a 30% decrease in global emissions from the livestock industry, or a 1.5% decrease in our global warming trajectory. If everyone decided to adopt a completely plant based diet, global emissions from the livestock industry would cease to exist and our global warming trajectory would decrease 5%, as opposed to a 2.278% decrease from switching technical mitigation solutions. Therefor, in order to make the greatest impact on greenhouse gases associated with animal agriculture, it is imperative that we reconsider our consumption of animal products.

Based on the findings regarding the potential decrease in greenhouse gases associated with the technical mitigation strategies analyzed, it is clear that future research must be done to come up with policies that ensure decreased consumption of animal products. Some of the policy-based solutions could include a carbon tax on animal products to decentivize purchasing these products due to the high quantity of emissions associated with their production. Another policy based solution could be a cap and trade system, in which the government sets a cap on emissions for a nation, and industries within the nation can trade their "right to pollute" through the use of permits. This could be a very effective strategy for cutting greenhouse gas emissions because it would ensure a significant decrease in greenhouse gas emissions for an entire nation, but it doesn't target one specific industry. The benefit of this solution is that it takes into account the societal problems associated with decreasing our consumption of meat. It is unrealistic to ask for an entire society to stop eating meat because achieving behavioral change among an entire nation is very difficult. In addition, there are many cultural practices and norms associated with consuming meat and animal products that would cease to exist in the event that the production of animal products are discontinued. Therefor, setting a cap on emissions for all industries ensures a certain decrease in emissions, but would not disrupt practices associated with the consumption of animal products.

Although it is unrealistic to expect the entire livestock industry to discontinue its production of animal products, it is possible to encourage individuals to decrease their consumption of meat through educational strategies. Educational solutions could include educating the public about the environmental harms and implications of eating meat to appeal to individual's green values, which may decrease individual meat consumption. Technical mitigation strategies alone are not enough to significantly decrease greenhouse gasses associated with animal agriculture, but expecting entire nations to discontinue their consumption of animal products is unrealistic. Therefor, at this point the most effective strategy to decrease emissions associated with the production of livestock would be to explore policy and education based strategies as alternatives to technical mitigation strategies to make the most positive environmental impact.

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