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Denmark's agricultural sector plays a significant role in greenhouse gas emissions, but effective strategies can be used to achieve carbon neutrality. This article examines four proposals to decrease agricultural greenhouse gas emissions: transitioning to plant-based food production, harnessing the benefits of the digital revolution in agriculture, using biogas from waste to lessen reliance on petroleum products, and implementing a carbon tax on agricultural production and land use.

Introduction

Denmark has set an ambitious goal of attaining carbon-neutral agriculture by 2050. Compared to the rest of the world, Denmark's approach to meeting this goal is notable for its comprehensive and multipronged approach. While many countries have made commitments to reducing greenhouse gas (GHG) emissions from agriculture, few have set such determined targets and taken proactive measures to achieve them. Denmark's focus on reducing emissions from livestock farming is particularly noteworthy, as this sector accounts for approximately 20% of the country's total GHG emissions, making it a crucial area for reducing the country's carbon footprint (Batini et al., 2020). To do so, Denmark has put into action a range of initiatives, with incentives for farmers to adopt renewable energy sources and reduce their use of fertilizers and pesticides as well as supporting the development of new technologies for reducing emissions from livestock. By investing in sustainable practices, Denmark has been able to make significant early progress toward its carbon-neutral agriculture goals. That said, there are some additional, tangible steps that can lead Denmark to ultimately reach its goal of GHG reduction in this sector. I discuss four approaches that have the potential to realistically further decrease agricultural GHG emissions within the next decade or so: 1) transitioning from animal-based to plant-based food production, 2) harnessing the benefits of the digital revolution in Denmark's agricultural industry, 3) using biogas from waste to lessen reliance on petroleum products, and 4) enacting a carbon tax on agricultural production and land use. As the world faces the urgent challenge of climate change, Denmark's commitment to carbon-neutral agriculture is a powerful example of what is possible when a country is willing to take bold action to protect the planet.

Background

Sustainability is a pillar of the Danish social fabric, and it plays a critical role in the economy of the country. From the push for electric vehicles in the transportation sector to the replacement of resource-intensive, nonrenewable energy with renewables, sustainability has been a major tenet of the Danish worldview. Denmark's goal to be a net zero GHG emission country by 2050 has resulted in regulations on heavy producers of GHGs. These include the imposition of carbon taxes on the energy and transport sectors, two of the largest contributors to GHG emissions. Notably, Denmark was one of the first nations to enact a carbon tax, in 1992 (Batini et al., 2020). However, there are still areas where GHG emissions can be lowered in Denmark, particularly in the agriculture sector.

The Danish agricultural sector has a long history and plays a significant role in the country's economy. Agriculture is one of the oldest and most traditional industries in Denmark and today remains an important source of employment and income for many rural and urban communities where the processing, distribution, marketing, and sales of agricultural products often take place. With a focus on sustainable practices and innovation, the Danish agricultural sector has become a world leader in modern farming methods, specifically in the areas of food safety, animal welfare, and environmental sustainability. However, the sector also faces significant challenges, particularly with respect to reducing GHG emissions and adapting to the impacts of climate change. Nonetheless, agriculture remains a vehicle through which a large amount of GHG emissions can be reduced in Denmark.

The agricultural sector has a considerable impact on the climate performance of Denmark. Each year, the Danish agricultural sector produces roughly 17.4

million tons of GHGs. With a 22% contribution, this is the third greatest source of GHG emissions in the nation, behind the energy and transportation sectors (Batini et al., 2020). There are distinct areas within the agricultural sector, however, that produce more GHGs than others. For example, cattle farming makes up a total of 41.8% of the GHG emissions (32.4% from direct emissions and 9.4% from related fertilizer storage and handling). Pig farming contributes 16.7% of the emissions (13.4% from direct emissions and 3.3% from related fertilizer storage and handling), while poultry results in 1.9% of the total GHG emissions (1.2% direct emissions and 0.7% from fertilizer storage and handling). Finally, the other 39.7% of GHGs come directly from growing crops on arable lands (Prag & Henriksen, 2020). The GHGs coming from farming are mostly methane, with some carbon dioxide (CO_2) emissions. Achieving carbon neutrality in agriculture is neither simple nor certain, because it depends on the effective development and application of several technical innovations and policy initiatives.

In recent years, the government has implemented a range of policies and initiatives to promote sustainable farming practices, thereby positioning the industry to continue to thrive in the years ahead. Various forms of co-regulation involving the government, corporations, and nongovernmental organizations address the climate change issues in Denmark's agricultural system. The main goal is to develop sustainable agricultural practices that reduce GHG emissions while ensuring food security and economic viability. Some strategies include establishing aggressive emission reduction goals, creating cutting-edge technology and management techniques, and assisting farmers with implementing these practices. Many laws applied at the national level are based on EU directives. One such environmental law is the Climate Action Plan for Agriculture. This act, introduced in 1991, tightened regulations on the application of manure to fields. A second, more refined action plan to enhance manure management and lessen nitrous oxide leakage into the soil and water was put into place in 2001. As a result of these acts, between 1990 and 2010, Denmark's GHG emissions decreased by 19.4% in the agricultural sector (Cooper et al., 2013). Such sustainable farming policies ensure a significant decrease in GHG emissions in the long run.

Additionally, in 2013, the Danish government introduced the Green Growth Plan, which comprises policies and initiatives aimed at promoting sustainable and climate-friendly farming practices. The plan was updated in 2020 with additional targets and measures to further reduce GHG emissions from the agricultural sector. One of the key goals of the plan is to decrease emissions from livestock production. The plan includes various actions, such as improving feed efficiency, decreasing the use of fertilizers, and increasing the use of biogas from manure. Moreover, the plan advocates for sustainable land use practices, such as agroforestry, which involves the integration of trees into agricultural landscapes to absorb carbon. Aside from promoting the use of cover crops to reduce soil erosion and nutrient loss and increase carbon sequestration in the soil, the Green Growth Plan prioritizes research and development, with the purpose of identifying new technologies and practices designed to decrease GHG emissions from the agricultural sector. The plan also highlights the need for collaboration between farmers, policy makers, and researchers to develop effective climate solutions for the agricultural sector. By addressing emissions from livestock production and promoting sustainable land use practices, the plan helps decrease GHG emissions from the agricultural sector and support a more sustainable and resilient farming system (Cooper et al., 2013). Alongside such existing national policies, it is crucial to consider additional GHG reduction strategies, including transitioning from animal-based to plant-based food production, taking advantage of the digital revolution, utilizing biogas, and legislating carbon taxation. Denmark can use such strategies to further reduce its agricultural emissions and contribute to the global efforts to mitigate climate change.

Strategies for reducing GHG emissions

To reduce GHG emissions in Danish agriculture, several strategies can be effective. One is transitioning to a plant-based diet (PBD), which has been shown to significantly reduce emissions compared to animal-based diets. Advanced farming technology can also help farmers optimize crop production and minimize waste, thus reducing emissions. The use of biogas from cattle farms can further reduce emissions by converting animal waste into a resource for energy production. Finally, imposing a carbon tax on different segments of the agricultural sector can incentivize sustainable practices and encourage emissions reduction. These solutions address various aspects of the agricultural sector and emphasize the importance of adopting multiple approaches to reduce GHG emissions.

Plant-based food production

The production of pork and dairy products comes at a considerable environmental cost. According to re-

cent studies, Danish agriculture, primarily pork and dairy production, generates approximately 17.4 million tons of GHGs annually, measured in CO_2 equivalents (CO_2e) (Searchinger et al., 2021). Among the solutions to the issue of excessive emissions from animal husbandry is plant-based meat replacements, and Denmark, like other nations, has opportunities to enter this market. A PBD refers to a wide range of eating habits that place a greater emphasis on plant-based foods and less on meat (Hemler & Hu, 2019). This reorientation has the potential to help Denmark reach its aggressive target of becoming carbon neutral by 2050.

PBDs can reduce GHG emissions in several ways. It is estimated that with full implementation of a PBD, Denmark can reduce emissions by 13.6 to 20.2 metric tons CO_2e (58% to 86%), provided domestic production of cattle, pig, and chicken is reduced by 76.2%, 21.1%, and 88.2%, respectively (Prag & Henriksen, 2020). Methane, a strong GHG, is produced by livestock, primarily cattle but also pigs and chickens; therefore, reduced meat consumption can decrease animal methane emissions. Reducing the demand for meat would also decrease the energy, water, and land required for food production; thereby, the carbon footprint of meals can be reduced, since some plant-based foods, such as legumes, nuts, and seeds, take fewer resources to produce, releasing fewer GHG emissions per calorie of food produced. Next, nitrous oxide, another GHG, is known to be produced by livestock feeds that contain corn and soy, which require nitrogen-based fertilizers, such as ammonia, urea, and ammonium nitrate, to grow. For PBDs, fewer nitrogen-intensive crops are required, minimizing GHG emissions. Aside from the reduction of GHGs, PBDs can lead to a median land use reduction of 15% for diets that substitute certain plant-based foods for meat (Aleksandrowicz et al., 2016) and 50% for vegan diets (Fresán & Sabaté, 2019). Diets based on plants can lessen the need for livestock grazing or to grow feed crops. In other words, there will be less land used for the purposes of breeding animals. In an ideal world, this land can be set aside for planting trees to aid in the overall reduction of GHGs for Denmark.

A global healthy reference diet has recently been suggested by the EAT–*Lancet* Commission on Food, Planet, Health,[1] which may be a great starting point for implementing PBDs in Denmark (Willett et al., 2019). The EAT–*Lancet* emphasizes that the scientific targets for the healthy reference diet are based on a substantial body of knowledge on foods, dietary patterns, and health outcomes. The amount of meat in the EAT–*Lancet* reference diet is around one-third of what Danes eat, with slightly more fish than the typical Danish diet (Pedersen et al., 2015). By switching from current national diets to the EAT–*Lancet* Commission's reference diet, it is calculated that this change could prevent about 25% of all premature deaths worldwide (Wang et al., 2019).

The EAT–*Lancet* reference diet must be modified to account for national preferences and settings, such as food culture, local food availability, nutrient content, and national dietary requirements. A recent study by researchers from the Technical University of Denmark assessed how the EAT–*Lancet* reference diet could be used to create a culturally appropriate and nutritionally adequate PBD for Denmark. The Danish food data were analyzed to modify the EAT–*Lancet* reference diet, and it was changed to conform to the Danish Dietary Recommendations and the Nordic Nutrition Recommendations. The Danish-adapted PBD is an example of a healthy diet with reduced meat intake and few fortified foods, with serving sizes within the guidelines of the Danish food-based dietary guidelines and EAT–*Lancet* reference diet. In the study, the suitability of a PBD in Denmark was recognized along with its potential to be established successfully with a recommended weekly meat consumption of about 350 g if consumption of legumes is increased (Willett et al., 2019).

Gradual implementation is necessary for transitioning toward a PBD. One approach is to reduce meat consumption by serving smaller portions at restaurants and promoting the substitution of meat with plant-based proteins. These tactics have been proven to effectively reduce meat purchases and consumption (de Gavelle et al., 2019). However, before incorporating PBDs in Denmark, it is crucial to consider the quality of plant-based foods in public health initiatives aimed at reducing chronic diseases (Baden et al., 2019). Educating people about nutritionally adequate PBDs is also essential to preventing unintended health consequences, such as micronutrient deficiencies (Tuomisto, 2019). Ultimately, transitioning to a plant-heavy diet is a long-term solution that can help Denmark reduce the 17.4 million tons of GHG emissions generated by the agricultural sector to a more acceptable level.

The digital revolution

Currently, the physical, biological, and digital worlds are increasingly blended in what some observers are

[1]The EAT–*Lancet* Commission, established in 2015, brings together specialists in nutrition, health, and sustainability to work on the interconnected problems of environmental sustainability and human health.

calling the fourth industrial revolution. An abundance of data gives farmers the ability to track and manage the entire food supply chain, make smarter judgments, and produce more sustainably. The use of digital technology and automation on farms has significantly increased in recent years. Danish farmers can now accurately determine the requirements for fertilizer, pesticide, herbicide, and water in their fields thanks to remote sensing. Precision farming (PF),[2] controlled traffic farming,[3] and global positioning (GPS) technology in the agricultural sector can aid in reducing GHG emissions, enabling farmers to optimize resource use, reduce waste, and make informed decisions about crop management. PF technology allows farmers to apply fertilizers, pesticides, and water only where they are needed, reducing waste and minimizing the release of GHGs associated with the production and transportation of these inputs. Denmark has been using PF for about 10 years. The early adopters began with yield mapping and monitoring before moving on to applying fertilizers at variable rates, mostly lime and to a lesser extent nitrogen. The early PF practitioners were technical enthusiasts, and as of now, 400 Danish farmers (or around 9% of the cereal acreage) have implemented some site-specific and GPS-related technology on their farms (Lundø & Larsen, 2018). With GPS-guided equipment, farmers can avoid overlapping the plowing, seeding, fertilizing, and harvesting passes over their fields, thereby reducing fuel, seed, and fertilizer consumption and associated GHGs. In recent years, controlled traffic farming has included auto-guidance and extremely precise real-time kinematic GPS to its field management strategy. Utilizing this technology, agricultural vehicles can travel the same path across a field year after year, minimizing soil damage and possibly increasing yields. By restricting machinery to specific lanes, controlled traffic farming reduces the amount of field area that is compacted and therefore the amount of fuel needed to move machinery over the field. In the long term, the use of these precision technologies means that farms will use less fossil fuel to operate machinery as well as fewer inputs of seed, herbicides, and pesticides.

If agricultural technology is so potent and has the capacity to reduce the production of GHGs, why are only a small number of farms using it? The cost associated with the implementation of the equipment remains the biggest factor. Expenditures are too high compared to the projected benefits, according to 50% of the farmers who do not use PF equipment. As a result, the most frequent justification for rejecting new technologies is expense. Next, soil variance can hinder the implementation of these technologies, because it can cause inconsistent results due to differences in nutritional composition, drainage patterns, and water-holding capabilities. Finally, lack of understanding and, more importantly, adherence to traditional farming practices are other reasons why PF technology has not yet been widely adopted (Lundø & Larsen, 2018). However, as technology advances, it is fair to assume that the cost of these devices will go down, and they will be more thoroughly integrated into Danish farms.

Biogas

Manure management is the source of 2.7 million tons, or around 16% of Denmark's agricultural production emissions (Searchinger et al., 2021). Because they account for 93% of these manure emissions, the focus is on pigs and cattle. Methane makes up around three-quarters of these emissions and nitrous oxide about one-fourth. Methane is estimated to have a global warming potential that is 28- to 36-times greater than that of CO_2 over a 100-year time horizon. However, CO_2 is a more prevalent GHG in the atmosphere and has a longer atmospheric lifetime than methane. This means that while methane is more potent, CO_2 has a greater cumulative impact on climate change over time. Therefore, both methane and CO_2 are essential considerations when addressing GHG emissions and climate change. As such, Danish policy has made controlling manure emissions a top priority, and this includes generous incentives to adopt biodigester technology that decomposes this waste and then utilizes the resulting biogas.

Biodigesters use an anaerobic process to break down manure from farm animals or other sources of organic waste. Manure, especially from pigs, which is easily managed, is collected and placed in an enclosed container, known as a digester, and allowed to decompose without oxygen. This process produces biogas as well as a nutrient-rich residue (digestate), which can be used as fertilizer. The biogas can be utilized as a source of energy for several purposes, including the production of electricity, heating, and fuel for vehicles. The organic material needed to make biogas is continuously created by natural processes, and the CO_2 emitted during biogas combustion is balanced by the CO_2 absorbed by plants during photosynthesis, making it a renewable energy

[2]PF is an agricultural management approach that uses advanced technologies, such as remote sensing, GPS, drones, and machine learning, to optimize crop production, reduce waste, and minimize the environmental impact of farming.

[3]Controlled traffic farming is a precision agriculture technique that involves restricting heavy field machinery to specific, permanent traffic lanes, leaving the remaining area untouched for crops.

source. In addition to being environmentally friendly, biogas can drastically lower GHG emissions.

Danish pig farms have been shown to exhibit financial benefits through biogas production efforts and are environmentally beneficial through CO_2 reduction techniques. Biogas production can be profitable thanks to subsidies under renewable energy schemes, with achievable payoffs based on farm size and biogas infrastructure investments made per farmer. Decentralized biogas production can reduce GHG emissions and create jobs across different sectors, including installation engineers, farmers and farm workers, input suppliers, and technology partners (Jacobsen et al., 2014). This makes biogas generation a more impactful solution than larger-scale industrial projects. Denmark's pig farming sector has opened doors toward a more sustainable approach within GHG emission reduction targets set nationally while offering economic gains via innovative solutions developed here.

Carbon taxation

One of the most effective, yet controversial, measures to reduce GHG emissions in Denmark is a form of tax known as carbon taxation. Carbon taxation is based on the idea that those who create carbon pollution must pay for the damage that it causes. This taxation incentivizes households and businesses to reduce their GHG emissions to avoid having to pay the tax. The current landscape of carbon taxation in Denmark entails the green CO_2 tax act of 1992, which ensures that emissions from energy generation, the combustion of waste, and the usage of coal, gas, and oil are taxed. The tax is 167kr (approximately $24) per ton of CO_2 released as of 2021. Industries that make up 35% of the total Danish GHG emissions, including those involved in energy production and transportation, are subject to the levy (Ghazouani et al., 2020). Although Danish farmers who use fossil fuel–powered farming equipment must pay the carbon tax, there are no explicit policies imposed on the agricultural sector, which accounts for 20% of the total GHG emissions in Denmark. To reach carbon neutrality in the Danish agricultural sector, it is critical to have a carbon tax policy in place for agricultural emissions (Batini et al., 2020).

By introducing an agriculture-specific carbon tariff, the Danish agricultural sector can benefit from the reduction of emissions and adoption of more sustainable practices. Although the current carbon tax on fossil fuels does not specifically target the agricultural industry, it does have an impact on farmers whose equipment is heavily reliant on fossil fuels. Farmers therefore have a financial incentive to invest in renewable energy sources or implement low-emission farming practices to avoid paying the costs related to the usage of fossil fuels. To further incentivize farmers, the government can provide them with tax rebates if they adopt sustainable practices. For example, farmers who use renewable energy sources can receive a tax rebate for their investment. The tax rebate for investment in renewable energy sources can be a percentage of the total investment, such as a 30% tax rebate for investments in solar panels. Similarly, the Danish government can also create a carbon credit market where farmers and agricultural businesses can earn credits for reducing their emissions. These credits can then be sold to other businesses that need to offset their emissions. For example, a farmer who adopts low-emission farming practices can earn carbon credits and sell them to a company that needs to offset their emissions (Batini et al., 2020). These measures can ensure that in the long run, emissions from fossil fuels are heavily reduced from the agricultural sector.

Furthermore, carbon taxation in the Danish agricultural sector can encourage the new technologies that can reduce GHG emissions. Such new technologies require significant investments in research and development. Carbon taxation can provide the necessary financial incentives to encourage farmers and agricultural businesses to invest in these technologies, leading to a more sustainable and environmentally friendly agricultural industry. For instance, research can be conducted to improve the efficiency of livestock production, such as reducing methane emissions from cattle through changes in feed or breeding practices. Also, precision agriculture technologies can be improved to optimize the use of fertilizers and reduce nitrous oxide emissions. These new technologies could not only reduce GHG emissions but also improve the efficiency and productivity of the agricultural sector. Ultimately, by promoting the adoption of new technologies, paid for through increased carbon taxation, the Danish agricultural sector can reduce its carbon footprint, improve its efficiency, and maintain a competitive edge in the global market.

The introduction of carbon taxation in Danish agriculture can have several drawbacks. It can put farmers at a disadvantage compared to producers in countries with no or lower carbon taxes, particularly affecting small farmers who may struggle to pass on increased costs to consumers or invest in emissions reduction technologies. This may lead to a decline in competitiveness and market share, especially in the export market. Additionally, implementing a carbon tax on agriculture is challenging due to the diffi-

culty in measuring and monitoring emissions from farming activities, especially from livestock. Distinguishing between various sources of emissions can also make it difficult to determine who should bear responsibility for the tax (Key & Tallard, 2011).

To mitigate the challenges of carbon taxation on the agricultural sector, careful planning of policies can be helpful. Carbon border adjustment mechanisms[4] can be introduced to prevent carbon leakage[5] and provide protection to domestic producers from unfair competition, thus addressing competitiveness concerns. Smaller farmers could receive financial incentives or subsidies to assist them in adopting emissions reduction technologies. The administrative complexity related to measuring and monitoring emissions can be resolved through the provision of guidance and support to farmers to ensure accurate calculation of their emissions, including the provision of emissions measurement tools and standard emission factors for different agricultural activities. Simplification of the tax system and support for tax compliance can also reduce administrative burdens. The government could invest in research and development to improve data collection techniques and create precise emission rates, working with farmers and agricultural organizations to obtain information and develop solutions for emission reduction. Finally, policy makers can structure the tax system to incentivize emissions reduction, providing financial incentives to farmers who switch to more environmentally friendly techniques and offering tax breaks for investments in technologies that reduce emissions, rather than solely imposing penalties for emitting GHGs to avoid rebound effects (Key & Tallard, 2011).

Conclusion

Denmark's agricultural sector is a significant source of GHG emissions, but there are effective strategies that can help reduce emissions and achieve carbon neutrality. These strategies include transitioning to plant-based food production, using digital technologies to improve efficiency, promoting biogas production, and implementing carbon taxation. Denmark's advanced agricultural sector provides an opportunity to lead the way in reducing emissions. Policies that support sustainable and healthy diets can help reduce emissions and promote public health. Digital technologies, such as PF and data analytics, can help reduce inputs, increase yields, and reduce emissions. Biogas production from animal waste and other organic materials can be used for heat and power generation, transportation, and as a substitute for fossil fuels. Denmark's existing carbon tax system can be further developed to provide more targeted support for emissions reductions in the agricultural sector. Collectively these suggestions would go a long way toward helping Denmark achieve its carbon neutral goals, while at the same time serving as a model for consideration by other nations.

[4]Carbon border adjustment mechanisms are techniques for pricing carbon emissions from the manufacture of commodities entering the EU fairly and for promoting cleaner industrial output in non-EU nations.

[5]The term, carbon leakage, describes the potential outcome if corporations relocate their output to nations with looser emission regulations due to the expenses associated with implementing climate policy.

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