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Last week, global leaders announced a commitment to reducing global methane emissions. In a previous blog post, I briefly reviewed some of the innovative strategies to reduce methane emissions from agricultural livestock and rice operations, which have the potential to combat a significant source of global greenhouse gas emissions. In this post, I will describe the set of tools needed to drive those reductions in jurisdictions around the world: methods for creating methane emissions inventories and setting baselines; regulations, incentive mechanisms, and cap-and-trade programs to encourage or require reductions; and measurement, reporting, and verification (MRV) at the facility-level to track compliance.

## Emissions Inventorying and Baselining

The first step in regulating agricultural methane emissions (and emissions in general) is to develop an accurate inventory of emissions, which can be used to set a baseline for future targets. Methane emission estimates can be built via either a bottom-up or top-down approach. A bottom-up approach takes in ground-level information regarding methane producers and, where necessary, empirical assumptions about their methane production (e.g., generic ruminant emissions factors for different livestock) to "build up" a methane emissions estimate at the desired geographic scale. For example, county-level enteric emissions estimates for cattle can be calculated from dry matter intake, methane emission factors, and total number of cattle. Similarly, a manure methane emissions estimate may consider factors such as the number of animals producing manure, qualities of the manure, and the method of manure management. A rice emissions estimate could consider factors like the area used for rice production and water management method, among many others.

A top-down approach begins with atmospheric emissions as recorded by sensors or satellites which can then, by a variety of methods, be attributed to geographic regions or particular categories of emitters. This can be achieved using mathematical modeling, extrapolating from detected gas ratios, or by combining top-down information with ground-level inventory data or bottom-up priors. Generally, emissions inventories appear to deliver lower estimates than top-down methods; top-down measurements capture all observed emissions while bottom-up methods only consider sources explicitly accounted for in a model. And, both methods are subject to typical uncertainties associated with assumption-driven estimation and modeling.

Ultimately, a mixture of both approaches will likely be needed to comprehensively inventory and baseline agricultural methane emissions.

## Agricultural Methane Regulation

Agricultural methane policies, where they exist, tend to take predominantly three forms: regulation, cap–and–trade programs, and government incentive programs. California has passed a series of bills which begin to address agricultural methane: SB 605, SB 1383, and SB 1122, and it appears to be the only major jurisdiction within the United States to have done so. SB 605 (2014) took the first step in methane-specific policy, directing the state's Air Resources Board to create "a comprehensive strategy to reduce emissions of short-lived climate pollutants" such as agricultural methane. SB 1383 (2016) explicitly mandated a 40% reduction in methane released as a product of manure management in the dairy and livestock sectors alongside a 40% reduction in overall methane emissions statewide (including, e.g., from oil and gas and other agricultural sources) by 2030. The bill authorizes the Air Resources Board to initially implement incentive-based strategies to achieve reductions, and directs it to implement an enforceable regulatory strategy for manure methane beginning in 2024 if the strategy meets several criteria such as technological, economic, and infrastructural feasibility. (The bill does not include specific direction for enteric or rice emissions reductions, but they are covered by the generic methane emission reduction requirement.) SB 1122 (2012) broadly promotes bioenergy, and requires 90 megawatts of production specifically from agricultural sources – providing an early incentive for use of dairy digester gas. The Air Resources Board recently released a report on progress toward SB 1383 goals, identifying substantial success in incentive programs (discussed below) and significant further developments needed to reach the 2030 target.

Internationally, New Zealand passed the Climate Change Response (Zero Carbon) Amendment Act of 2019 which targets a 24-47% reduction in biogenic methane emissions by 2050, and a 10% reduction by 2030. This appears to be the only national level agricultural methane target currently in law. The act does not specify the mechanism by which the reduction must occur, but the relevant policy is in development.

While laws or regulations explicitly targeting agricultural methane are currently uncommon, modifications to existing law or new regulations are expected in the European Union and New York State. Additionally, agricultural methane emissions reductions can fall under existing green energy regulatory frameworks such as the Non-Conventional Renewable Energy Law in Chile, which mandates a modest but increasing fraction of energy be generated via "non-conventional renewable energy sources" such as biomass, which can be satisfied via anaerobic digestion.

## Cap-and-Trade Programs

Cap-and-trade programs commodify emissions reductions to incentivize the most financially efficient solutions among emitters. Agricultural emissions reductions do not always qualify, in part because they can be difficult to accurately measure. However, the California program allows for a small portion, between 4% and 8% depending on the applicable year, of the compliance obligation of a firm to be satisfied by emission offsets – which include agricultural emissions-mitigating projects such as implementing anaerobic digesters or adopting improved rice cultivation practices. These offset protocols serve the dual purpose of facilitating overall compliance and incentivizing development of new emission reduction strategies. Similarly, the Australian Emissions Reduction Fund provides credits in return for a host of emissions-abating practices such as utilizing feed additives like nitrates and adopting improved manure management practices.

In some jurisdictions, other credit mechanisms such as credits issued for producing renewable energy for transportation, or nutrient management credits issued for preventing water contamination, can further incentivize the adoption of anaerobic digesters which potentially address both issues.

**Incentive and Subsidy Programs**

Finally, governments can implement direct incentive programs which fund or otherwise facilitate the implementation of agricultural methane reduction measures. California's Dairy Digester Research and Development Program (DDRDP) and Alternative Manure Management Practices Program (AMMP) are both funded by cap-and-trade via the California Climate Investments Program (CCI). The DDRDP funds the application of anaerobic digesters while the AMMP invests in manure management emissions mitigation strategies which do not require a digester. Current AMMP projects are anticipated to reduce GHG emissions by about 1.1 million metric tons in $CO_2$ equivalent over five years, while the set of DDRDP projects funded between 2014 and 2018 are anticipated to generate about a 12.8 million metric ton reduction in $CO_2$ equivalent over ten years. The EPA AgSTAR program offers technological and logistical guidance to those seeking to implement anaerobic digester systems, and, in several countries, tax incentives or payment schemes regarding biofuel production or consumption are offered.

**Monitoring, Reporting, and Verification**

Monitoring, reporting, and verification (MRV) of actual emission reductions achieved is a vital component of any policy regime to ensure targets are met and enforcement action is taken. While both bottom-up and top-down inventorying methods can assist with MRV, the methods most pertinent to an MRV regime for agricultural methane emissions will be those that can verify compliance via direct measurement. For enteric emissions, this would involve measuring methane emissions as they are released by the animal. This can be done by taking samples via a respiration chamber, livestock face masks, or a chemical tracer method, among other methods. The appropriate method will vary depending on several factors; for example, while respiration chambers tend to produce the most reliable results, they can influence the outcome of the measurement by altering the animal's behavior, and can be rather costly. Unfortunately, recorded emissions can vary across measurement methods which must be considered in evaluating their outputs, though measures can be taken to mitigate error.

Direct measurement of emissions from stored manure and rice paddy is straightforwardly accomplished. Closed-chamber systems can gauge emissions from samples of manure and rice paddy alike to track facility performance. In all cases, representative samples can be used to estimate and track facility-wide emissions over time – a core component of any policy or regulatory effort to reduce emissions. For example, innovative manure slurry sampling and modeling methods may facilitate the tracking of manure emissions, and improved rice paddy emissions sampling protocols may increase the accuracy of rice paddy emissions estimates.

## Conclusion

Ultimately, tackling the problem of agricultural methane emissions will require a combination of scientific and policy action in multiple iterations as strategies and technologies evolve over time. While the emission reduction challenge is substantial, the scientific, policy, and MRV opportunities which exist to meet it are promising.