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# An evaluation of the social and private efficiency of adoption: Anaerobic digesters and greenhouse gas mitigation

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ABSTRACT

Climate science has begun to recognize the important role of non-carbon dioxide greenhouse gas emissions, including methane. Given the important contribution of methane, anaerobic digesters (ADs) on dairy farms in the U.S. present an opportunity to reduce greenhouse gas (GHG) emissions. We quantify the social and private costs and benefits of ADs that have been adopted in California and find that, despite high initial costs, large reductions in GHG emissions bring significant social benefits and represent good social investments given a $36 per-ton social cost of carbon. Subsidies that lower the initial private investment cost can help align socially and privately optimal adoption decisions.


## 1. Introduction

Evidence is mounting that human economic activity is influencing the Earth's climate in ways likely to be costly in the future (IPCC, 2013). More specifically, climate science has begun to recognize the role of non-$CO_2$ greenhouse gases (GHGs) from the agricultural sector (Hyman et al., 2003). In 2009, the U.S. Secretary of Agriculture announced an agreement to decrease GHG emissions on farms by 25% prior to 2020 with anaerobic digestion as the primary means to meet this goal (USDA, 2009). In 2012, the U.S. agricultural sector was identified as contributing 8.1% of total GHG emissions within the U.S. Of this, 25% was a result of methane emissions from enteric fermentation and manure management, mostly from beef and dairy cattle (USDA-EPA, 2012).[1]

The role of agriculture in GHG emissions suggests that altering farm practices provides an opportunity to mitigate climate change. The adoption of anaerobic digesters (ADs) on livestock farms represents a promising opportunity for cost-effective GHG mitigation, especially on dairy farms (Key and Sneeringer, 2011). ADs are part of the livestock manure handling system and typically consist of covered lagoons or tanks. ADs are designed to stabilize manure and optimize the production of methane through the biological anaerobic digestion process. This methane is captured and used to produce energy. Adopting ADs significantly lowers methane emissions from livestock (USDA-EPA, 2012) since methane released from stored manure in anaerobic conditions (either liquid slurries or lagoons) can be captured and used to produce energy. This provides livestock producers with an opportunity to enhance their environmental stewardship while jointly reducing the need to purchase energy and creating an additional source of revenue via the sale of excess energy produced on farm. Furthermore, farmers can receive financial payments for decreasing GHGs via a carbon market price. Carbon markets provide an opportunity to internalize the cost of methane emissions and efficiently incentivize AD adoption. However, carbon markets such as the *California Carbon Market* (Cal-EPA, 2012) have not had prices that reflect current estimates of the social cost of carbon (Tol, 2008). In the absence of GHG markets, federal, state, and local governments have implemented subsidies to help cover AD costs.

To date, there has not been a study that evaluates the social and private net benefits of AD adoption with and without subsidies using actual electricity production and prices. The objective of this paper is to examine ADs that have been adopted and determine if subsidy programs aimed at encouraging alternative energy production have been socially efficient investments. First, we evaluate the effectiveness of AD subsidies at reducing GHG emissions on CA dairy farms. Specifically, we construct a benefit–cost framework to

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[1] Methane, while shorter-lived in the atmosphere than $CO_2$, has a much higher capacity to trap heat. A unit of methane emitted today has a warming impact over 100 years that is 25 times greater than a unit of $CO_2$ (Shindell et al., 2009).

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quantify the private and social net benefits of 12 operating ADs in CA. This differs from much of the previous work which evaluates a "typical" adopter or simulates adoption. Secondly, we highlight the divergence between social and private benefits that occurs in the absence of a carbon price. In this situation, second-best policies such as subsidies can align socially and privately optimal investment decisions. We find that AD adoption on CA dairies has largely represented a good investment from society's perspective. While some ADs would likely have been adopted in the absence of subsidies, all ADs produce a total (social) benefit that exceeds the large upfront cost, assuming the AD is operated for its expected lifetime. Because a large portion of the benefits are external, adoption would not likely have occurred on most farms in the absence of subsidies. The lessons learned from this analysis provide insights to other semi-arid dairy farming regions in the U.S.

## 2. Background

Across the U.S., AD adoption has occurred principally on dairy and swine farms (EPA-AgStar, 2014). Focusing on dairy farms, ADs have been adopted in 27 U.S. states from herd sizes of 75 to 24,900 cows.[2] In 2004, 41 ADs were operational, including 29 on dairy farms (Lazarus and Rudstrom, 2007). Ten years later, 193 dairy ADs were in operation with an average herd size of 2146 cows (EPA-AgSTAR, 2014). This is over a 565% increase in the number of dairy ADs in operation, indicating a strong upward trend in adoption.

The prospects for AD adoption on US dairy farms have been widely studied with emphasis on the relationship between profitability and herd sizes (Gloy and Dressler, 2010; Key and Sneeringer, 2011; Gloy, 2011; Leuer et al., 2008; Lazarus et al., 2011), electricity sales (Bishop and Shumway, 2009), financing options (Gloy and Dressler, 2010; Lazarus and Rudstrom, 2007), and the effects of carbon offset credits (Gloy, 2011; Key and Sneeringer, 2011; Lazarus et al., 2011). AD adoption has the potential to bring private benefits through electricity production (Lee and Sumner, 2014; USDA-EPA, 2012). This lowers the quantity of electricity purchased while providing an opportunity to sell excess electricity to the grid. Because electricity production provides the greatest private benefit to AD adoption, higher electricity production capacity leads to higher gross benefits of adoption. In addition, some regions of the country have implemented a carbon pricing system. Specifically, CA created the *California Carbon Market* in 2012 and the north-eastern region of the U.S. developed *the Regional Greenhouse Gas Initiative* in 2008. If farmers receive carbon market payments for reducing GHG emissions, this increases the benefit of adoption. Many farms could benefit from carbon prices but in practice, few dairies have participated in these programs (Key and Sneeringer, 2011). Therefore, most dairies do not internalize a price for carbon.

ADs have been adopted outside the U.S., but incentive programs vary substantially across and within countries. In Europe, Germany is the largest adopter, with over 6000 ADs (both agricultural and municipal) followed by Austria with approximately 550. Adoption has been incentivized with investment subsidies, increased electricity prices received, and lower interest rates (Nordberg, 2004). While adoption incentives play a big role, other factors such as environmental policies and energy security also influence adoption (Wilkinson, 2011).

Despite private benefits to farmers, U.S. adoption has not been widespread (Lazarus and Rudstrom, 2007). The main reason cited is the large irreversible sunk investment cost of the AD (Enahoro and Gloy, 2008; Lazarus and Rudstrom, 2007; Gloy and Dressler, 2010). Earlier work has shown that large farms are more likely to produce sufficient electricity to cover high initial investment costs, though increasing capacity is costly. Even in the case of large farms, a carbon price is often necessary to incentivize adoption (Gloy, 2011). Financing can also represent a significant barrier to AD adoption. Lazarus and Rudstrom (2007) found that on a Minnesota dairy farm that adopted an AD, 42% of the cost was financed through debt, 22% by grants and subsidies, and the remainder covered through equity capital. Without these funding opportunities, the project would not likely have been feasible. Mechanical problems, lack of cooperation from utility companies, and design flaws are additional reasons for high failure rates (Morse et al., 1996).

Several studies have evaluated the economic viability of ADs on U.S. dairy farms, with a concentration on mid-west and eastern dairies. Stokes et al. (2008) used an option-value model to capture the value of waiting to invest in an AD. They found it was optimal to delay AD investment as uncertainty about the return to investment increased. Capital budgeting was used by Lazarus and Rudstrom (2007) to find that electricity pricing and loan conditions played the largest role in determining AD viability. Finally, Leuer et al. (2008) used stochastic capital budgeting to find that ADs on farms with more than 1000 cows had the greatest potential to be profitable.

Existing studies highlight that AD adoption has not been economically viable on most U.S. dairies even after internalizing the carbon price. Lazarus et al. (2011) and Gloy (2011) find that at a carbon price of $100, around 15% of dairies would adopt ADs. In the absence of carbon prices that align social and private incentives, other policies and innovative partnerships have been implemented to increase revenues and improve private economic feasibility (Bishop and Shumway, 2009). In practice, several subsidy programs exist at the federal (e.g., USDA's Environmental Quality and Incentives Program (EQIP)) and state (e.g., Dairy Power Production Program (DPPP) in CA) levels to encourage adoption.

We focus on the net private and social benefits of 12 ADs in CA that used public subsidy programs. California was chosen as the study area since it is recommended that anaerobic digestion occur in hot and relatively stable weather environments (Lee and Sumner, 2014). Secondly, lagoon digesters can more efficiently achieve anaerobic digestion in these regions without the use of heated tank which is needed in a plug-flow system.[3] Lagoon systems capture slightly less methane, they are significantly cheaper on average, and can represent a viable option for GHG mitigation in arid climates.

## 3. Theoretical model

We develop a framework for dairy AD adoption using a model of dynamic costs and benefits to assess the private and social viability of ADs.[4] When privately and socially optimal decisions diverge, policies can encourage individuals to make the socially optimal decision. The private model of the investment decision highlights the incentives that policy can influence in the absence of a carbon price. The social investment model includes private costs and benefits *plus* the external benefits of AD adoption. The results of this model can be used to assess the circumstances under which

[2] Arizona, California, Connecticut, Florida, Georgia, Iowa, Idaho, Illinois, Indiana, Massachusetts, Maryland, Michigan, Minnesota, Mississippi, Montana, New Mexico, New York, Ohio, Oregon, Pennsylvania, South Dakota, Texas, Utah, Virginia, Vermont, Washington, and Wisconsin.

[3] A plug-flow system contains an insulated and heated tank where gas is captured. A covered lagoon does not use a heating system. Plug-flow systems are commonly used in colder climates.

[4] The investment likely contains an option value (Dixit and Pindyck, 1994) that we do not treat here explicitly.