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Joleen C. Hadrich, Department of Agricultural and Resource Economics Colorado State University joleen.hadrich@colostate.edu

and

Dale T. Manning, Department of Agricultural and Resource Economics Colorado State University <u>dale.manning@colostate.edu</u>

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Factors affecting anaerobic digester adoption in the West

Joleen C. Hadrich and Dale T. Manning, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80526 joleen.hadrich@colostate.edu, dale.manning@colostate.edu

Introduction

• Recently, climate policy has recognized the role of non-CO₂ greenhouse gases (GHGs), particularly in agriculture. •In 2009, 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) •Dairy and swine farms are the most viable options for anaerobic digesters • What does this mean for dairy farms? *Methane is shorter lived in the atmosphere than CO₂, but has much higher capacity to trap heat. *One unit of methane emitted has a warming impact over 100 years that is 25 times greater than a unit of CO₂ (Shindel et al. 2009). *Anaerobic digesters (AD) on dairy farms represents a promising opportunity for cost effective GHG mitigation due to decreased methane emissions. Background *Dairy farms of all sizes (75 to 24,900 cows) have adopted ADs in 27 U.S. states. In the past 10 years, dairy ADs have increased from 41 to 193 operational (AgStar, 2014). *Electricity production provides the greatest benefit of AD adoption. *Despite benefits for farmers, AD adoption has not been widespread. *Dairies in the West have the greatest potential due to the number of cows and warmer climate for methane production. • What can be done to increase adoption? ⁴ Subsidy programs at a state and federal level \rightarrow EQIP (Environmental Quality Incentive Program) → DSPP (Dairy Power Production Program (available in California) *Carbon prices that align social and private benefits. **Research Objective** • Evaluate the effectiveness of subsidies for adoption of ADs that reduce GHG emissions on California dairy farms •Evaluate the divergence between social and private benefits that occurs in the absence of a carbon price. Methods Benefit-Cost framework Data 12 dairies in California that adopted ADs through the use of

public subsidy program

 \rightarrow Dairy1-Dairy8 (Marsh et al. 2009)

 \rightarrow Dairy9-Dairy12 (Cheremisinoff, Georgey, and Cohen, 2009) \rightarrow Supplemental information AgSTAR EPA (2014)

 Variables : electricity production and consumption, price paid and received for electricity, AD cost, operating costs, and total subsidies received. Farm level characteristics include herd size, AD capacity, and type of digester system.

Assumptions—financed the farmer cost with a 20 year loan at 7%, discount rate at 9%

							Digester of	ost		
				Cows	Total 1	Monthly	per kW	Digester co	st Electricity	Electrici
		In Operation	Capacity	Feeding	Digester C	Operating	capacit	y per cow	Demand	Producti
Dairy	System Type	(Jan 2014)	(kW)	Digester* (Cost** (\$) C	Costs (\$)	(\$/kW)	(\$/cow)	(kWh)	(kWh)
Dairy1	lagoon	Yes	75	365	334,680	329	4,462	917	244,500	252,792
Dairy2	lagoon	Yes	160	3,234	882,136	950	5,513	273	867,756	1,054,56
Dairy3	lagoon	Yes	300	5,616	2,498,038	6,200	8,327	445	10,898,400	2,133,08
Dairy4	lagoon	Yes	500	6,000	1,239,923	1,750	2,480	207	1,600,860	3,370,46
Dairy5	plug flow	No	180	1,100	802,810	1,500	4,460	730	279,768	453,16
Dairy6	plug flow	No	260	2,285	1,361,087	2,250	5,235	5 96	663,180	539,89
Dairy7	plug flow	Yes	160	2,566	720,605	560	4,504	281	867,000	1,098,63
Dairy8	plug flow	No	130	651	836,838	1,500	6,437	1,285	387,120	486,34
Dairy9	lagoon	Yes	80	360	625,000	1,102	7,813	1,736	698,615	430,072
Dairy10	plug flow	Yes	710	1,500 -	4,020,000	11,567	5,662	2,680	419,795	3,442,83
Dairyl l	lagoon	Yes	212	1,050	1,700,000	3,333	8,019	1,619	293,856	618,760
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		ding subsidies or	other grant fu							
			other grant fu	External Ben		-	(3)	(4)	(5)	
			other grant fu		efits of AD A	-	(3)	(4) A mual	(5)	
			other grant fu	External Ben		. (Annual	(5)	
	ster cost not inclu	ding subsidies or	other grant fu	External Ben (1)	(2)	G	ΉG	Annual Value of		
		ding subsidies or	other grant fu	External Ben (1) Methane	(2) Displaced	G Reduc	HG ction per	Annual Value of GHG	Avg. GHG	
	ster cost not inclu	ding subsidies or	other grant fu	External Ben (1) Methane Reduction	(2) Displaced CO2 Emissio	G Reduc ons Far	HG ction per m (mt	Annual Value of GHG Reduction* b	Avg. GHG enefit per cow	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3:	External Ben (1) Methane Reduction (mt CO2e/yr)	(2) Displaced CO2 Emissio (mt/yr)	G Reduc ons Far CO	HG ction per m (mt 2e/yr)	Annual Value of GHG Reduction b (\$/yr)	Avg. GHG enefit per cow (\$/cow/yr)*	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385	(2) Displaced CO2 Emissio (mt/yr) 140	G Reduc ons Far CO 1,	HG ction per m (mt 2e/yr) 525	Annual Value of GHG Reduction b (\$/yr) 54,895	Avg. GHG enefit per cow (\$/cow/yr)* 150	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385 12,271	(2) Displaced CO2 Emissio (mt/yr) 140 584	G Reduc ons Far CO 1, 12	HG etion per m (mt 2e/yr) 525 2,855	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777	Avg. GHG enefit per cow (\$/cow/yr)* 150 143	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385	(2) Displaced CO2 Emissio (mt/yr) 140	G Reduc ons Far CO 1, 12	HG ction per m (mt 2e/yr) 525	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647	Avg. GHG enefit per cow (\$/cow/yr)* 150	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385 12,271	(2) Displaced CO2 Emissio (mt/yr) 140 584	G Reduc ons Far CO 1, 12 22	HG etion per m (mt 2e/yr) 525 2,855	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777	Avg. GHG enefit per cow (\$/cow/yr)* 150 143	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385 12,271 21,310	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180	G Reduc ons Far CO 1, 12 22 24	HG etion per m (mt 2e/yr) 525 2,855 2,490	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3 Dairy4	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385 12,271 21,310 22,767	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180 1,865	G Reduc ons Far CO 1, 12 22 24 6,	HG ction per m (mt 2e/yr) 525 2,855 2,490 2,632	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647 886,753	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144 148	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3 Dairy4 Dairy5	External Ben (1) Methane Reduction (mt CO2e/yr) 1,385 12,271 21,310 22,767 6,048	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180 1,865 251	G Reduc ons Far CO 1, 12 22 24 6, 12	HG ction per m (mt 2e/yr) 525 2,855 2,490 4,632 299	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647 886,753 226,749	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144 148 206	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3 Dairy4 Dairy5 Dairy6	External Ben (1) Methane Reduction (mt CO ₂ e/yr) 1,385 12,271 21,310 22,767 6,048 12,563	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180 1,865 251 299	G Reduc ons Far CO 1, 12 22 24 6, 12 14	HG ction per m (mt 2e/yr) 525 2,855 2,490 4,632 299 2,862	Amual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647 886,753 226,749 463,022	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144 148 206 203	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3 Dairy4 Dairy5 Dairy6 Dairy7	External Ben (1) Methane Reduction (mt CO2e/yr) 1,385 12,271 21,310 22,767 6,048 12,563 14,108	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180 1,865 251 299 608	G Reduc ons Far CO 1, 12 22 24 6, 12 14 3,	HG ction per m (mt 2e/yr) 525 2,855 2,490 4,632 299 2,862 2,99 2,862 4,716	Amual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647 886,753 226,749 463,022 529,771	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144 148 206 203 203 206	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3 Dairy3 Dairy4 Dairy5 Dairy5 Dairy6 Dairy7 Dairy8	External Ben (1) Methane Reduction (mt CO2e/yr) 1,385 12,271 21,310 22,767 6,048 12,563 14,108 3,579	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180 1,865 251 299 608 269	G Reduc ons Far CO 1, 12 22 24 6, 12 14 3, 1,	HG ction per m (mt 2e/yr) 525 2,855 2,490 4,632 299 2,862 2,99 2,862 4,716 ,848	Amual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647 886,753 226,749 463,022 529,771 138,540	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144 148 206 203 206 203 206 213	
Total diges	ster cost not inclu	ding subsidies or	other grant fur Table 3: Dairy1 Dairy2 Dairy3 Dairy3 Dairy4 Dairy5 Dairy6 Dairy7 Dairy8 Dairy9	External Ben (1) Methane Reduction (mt CO2e/yr) 1,385 12,271 21,310 22,767 6,048 12,563 14,108 3,579 1,366	(2) Displaced CO2 Emissio (mt/yr) 140 584 1,180 1,865 251 299 608 269 238	G Reduc ons Far CO 1, 12 22 24 6, 12 14 3, 1, 10	HG ction per m (mt 2e/yr) 525 ,855 ,490 ,632 ,299 2,862 ,716 ,848 ,604	Annual Value of GHG Reduction b (\$/yr) 54,895 462,777 809,647 886,753 226,749 463,022 529,771 138,540 57,744	Avg. GHG enefit per cow (\$/cow/yr)* 150 143 144 148 206 203 206 213 160	



	(1)	(2)	(3)	(4)	(5)
				Annual	
			GHG	Value of	
	Methane	Displaced	Reduction per	GHG	Avg. GHG
	Reduction	CO2 Emissions	Farm (mt	Reduction*	benefit per cov
	(mt CO ₂ e/yr)	(mt/yr)	CO ₂ e/yr)	(\$/yr)	(\$/cow/yr)*
Dairy1	1,385	140	1,525	54,895	150
Dairy2	12,271	584	12,855	462,777	143
Dairy3	21,310	1,180	22,490	809,647	144
Dairy4	22,767	1,865	24,632	886,753	148
Dairy5	6,048	251	6,299	226,749	206
Dairy6	12,563	299	12,862	463,022	203
Dairy7	14,108	608	14,716	529,771	206
Dairy8	3,579	269	3,848	138,540	213
Dairy9	1,366	238	1,604	57,744	160
Dairy10	8,247	1,905	10,152	365,480	244
Dairy11	3,984	342	4,327	155,758	148
Dairy12	3,225	126	3,352	120,665	142

	(1)	(2)	(3)	(4)	(5)	(6) = (4) + (5)	(7)	(8)	(9)	(10)
	System Type	PV Private Costs (excluding subsidies)*	PV Private Costs (with Subsidy)	PV Private Benefits	PV External Benefits	PV Total Benefits	Adopt (if (4)>(2))	Optimal** Mitigation (if (6)>(2))***	Adopt with Subsidy (if (4)>(3))	Operating (1=yes, 0=no)
Dairy1	lagoon	324,423	190,639	346,313	501,116	847,429	yes	yes	yes	1
Dairy2	lagoon	864,176	392,501	844,303	4,224,480	5,068,783	no	yes	yes	1
Dairy3	lagoon	2,831,649	2,107,846	7,441,593	7,390,900	14,832,494	yes	yes	yes	1
Dairy4	lagoon	1,260,104	829,269	1,868,712	8,094,763	9,963,475	yes	yes	yes	1
Dairy5	plug flow	856,071	597,570	226,258	2,069,889	2,296,147	no	yes	no	0
Dairy6	plug flow	1,419,279	1,254,764	363,232	4,226,715	4,589,948	no	yes	no	0
Dairy7	plug flow	682,268	283,789	559,447	4,836,037	5,395,484	no	yes	yes	1
Dairy8	plug flow	885,392	545,341	221,982	1,264,671	1,486,653	no	yes	no	0
Dairy9	lagoon	659,223	304,215	314,293	527,121	841,413	no	yes	yes	1
Dairy10	plug flow	4,730,956	2,764,625	3,711,089	3,336,300	7,047,389	no	yes	yes	1
Dairy11	lagoon	1,829,954	795,950	435,544	1,421,845	1,857,389	no	yes	no	1
Dairy12	lagoon	721,487	273,026	237,718	1,101,492	1,339,210	no	yes	no	1

***With a carbon price of \$36 per MT of CO2e

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Summary Statistics

- Average cost of lagoon is \$1.1 million while plug-flow \$1.5 millions
 - agoon produces 573 kWh/cow while the plug-flow oduces 824 kWh/cow, on average
 - verage digester cost per cow and kW of capacity ries greatly \rightarrow larger dairies tend to have higher pacities, but not necessarily lower costs.
 - In average, subsidies covered ~50% of the initial vestment

esults

- all 12 cases, the social benefit of AD adoption ceeded its cost
- Only 3 ADs were privately optimal without subsidies
- ADs were not privately optimal even with a subsidy \rightarrow 3 of these ADs have shut down (built in 2004)
- \rightarrow other 2 still operational (built in 2008)
- **May need higher upfront subsidies to make the AD** ofitable on an annual basis. This decreases annual ancing costs and could make the investment socially timal.
- ssuming ADs are financed has a qualitative impact on e present value of AD costs.

goons vs. Plug-flow

- lectricity production is lower for lagoon digesters an plug-flow digesters. However, the larger upfront sts for plug-flow digesters make them less onomically feasible.
- of the 7 dairies with lagoon systems were privately timal without subsidies.
- of the 5 plug-flow digesters should not have been opted even with subsidies. In all 3 of these cases, the **Os have shut down.**

nsitivity to carbon prices

- carbon price of \$12/MT of CO₂e, less than 2/3 of ADs are socially optimal investments
- •At \$24/ MT of CO₂e, 90% are efficient investments •Carbon price that reflects the social cost of carbon (\$30-40/ton) aligns social and private incentives.

Conclusions

- ADs on dairy farms in semi-arid areas can efficiently reduce emissions on GHGs on farms
- •Results show a notable difference between lagoons and plug-flow digesters.
- •Loan financed ADs can be a socially optimal option to manage GHGs
- •Important to balance the need for a subsidy with the possibility of over-subsidizing

Further Considerations • Collect farm-level data via survey methods to have a larger data source to perform statistical and regression analysis.

