Greenhouse gas reduction policy and size distributions of dairy farms

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During the last decade, the dairy industry in the United States has faced growing economic and policy challenges. Among the most important challenges have been those related to waste management and its environmental implications. Manure handing has implications for ground water quality, stream water quantity, and local air quality. Manure handling also affects greenhouse gas (GHG) emissions, which has been subject to increasing regulation and scrutiny in some places. Among the short-lived GHG emissions, a big share comes from methane emissions produced livestock. Dairy cows contribute much of livestock methane production, and the majority of manure-based (as opposed to enteric) methane emissions. Methane for dairy cows is especially important in states where the dairy industry is large, such as California (Lee and Sumner 2014 and CARB 2017).

Greenhouse emissions from bovines raise policy issues globally that have important implications for the economic outlook of several food products and industries, including milk and the dairy industry. These understanding these implications are crucial for the U.S. dairy industry that has faced economic pressures from relatively low milk prices and high feed prices in some years. Dairy farm margins have been tight especially for smaller dairy farms that have exited the industry in large numbers. That has been true nationally and in California, where even smaller dairy farms may be considered large by the standards of some other regions (MacDonald and Newton 2014).

In order to meet short run GHG reduction targets, California regulations on methane emissions from manure will be soon imposed on confined animal feeding operations, and most importantly dairy farms (CARB 2017). Manure management processes, such as scraping and drying manure, using anaerobic digestion, or use of more pasture-based dairy farming, may help to reduce methane emissions. Methane digesters are one potentially useful technology, but others are also being evaluated, especially for smaller dairy farms (CDFA 2019). An important topic is implications for relative costs of production or profitability.

This study investigates the economics of alternative manure managements practices (on size economies and other size and scale implications for dairy farms. We quantify the estimated methane emissions and document estimated costs of alternative technologies currently used (or that may be used) to manage manure. We evaluate the economic effects of the adoption of these strategies on different sizes of commercial dairies, and project the economic impacts of these new regulations, focusing on small dairies in California.

Policy Background

The California livestock industry contributes to 54% of the total methane emissions in the state. Manure handling from dairy farms contributes to a 45% of the total livestock methane emissions. Enteric fermentation from dairies contributes to a 37% of the total livestock methane emissions. From the 18% remainder, enteric fermentation from beef cattle contributes to 16%, while manure from beef cattle only 2% of the total in state livestock methane emissions. (CARB 2017 and Lee and Sumner 2018) The major source of methane emissions from dairy manure is the use of open lagoons to store manure before it is transferred to farm fields. Anaerobic bacteria in open lagoons digest nutrients in cow manure releasing of methane emissions (Kaffka et al 2016).

In 2016, the California Senate Bill-1383 ("Short-lived climate pollutants: methane emissions: dairy and livestock: organic waste: landfills.") was approved as law to establish a series of regulations for reducing "short-lived climate pollutants", including black carbon (soot), methane (CH4), and fluorinated gases (F-gases, including hydrofluorocarbons, or HFCs).

Therefore, one of the targets is to cut dairy methane emissions by 40% below current levels in 2030 by capturing or altogether avoiding methane from manure at dairies, and pursuing opportunities to reduce methane emissions from enteric fermentation. Regulations imposing these targets will be mandatory starting in January 1st of 2024 (CARB 2017 and Lee and Sumner 2019).

California law provided some limited funding to create positive incentives for adoption of practices that reduce methane emissions from dairy manure partly as demonstrations projects. The California Department of Food and Agriculture (CDFA) created programs to subsidize the implementation of centralized digesters and alternative manure management practices (CDFA 2019).

During the years 2015, 2017, and 2018, the CDFA subsidized the implementation of digesters in 64 dairies with over $114 million, which represents 36% of the total capital cost of those projects. During the years 2017 and 2018, the CDFA subsidized the implementation of alternative manure management practices (AMMP) in 58 dairies with over $31 million, which represents 87% of the total capital cost of those projects (CDFA 2019).

Dairy Industry Background

California has about 1.7 million of milking cows and about 1300 dairy farms. Milk is the top revenue commodity in California and California produces far more milk than any other state in the United States. More than 90% of milk production is now in the San Joaquin Valley, which has dry summary and much irrigated cropland. It is also a region with water quality and local air quantity concerns that affect manure handling and regulations on electricity generation. The region also manufactures a full range of processed dairy products, so that the economic scope of the California dairy industry extends far beyond the farm gate. The economic contribution to the California economy is about $7 billion in direct farm revenue $20 billion contribution to Gross State Product and about 180,000 jobs (Matthews and Sumner, 2019).

San Joaquin Valley dairy farms average about 1700 cows and confinement systems where cows are kept in feedlot style pens and fed hay, silage, grain and oilseed rations as well as a long list of local feeds such as almond hulls or citrus pulp or tomato pumice. These operations have typically flushed manure into open lagoons that then is used as crop fertilizer. The few dozen dairies in coastal Northern California have much smaller herds and are often at least partially pasture-based. This region also has most of the organic dairies in the state (Matthews and Sumner 2019).

Economics of Size Distribution of Dairy Farms

Data on the size distribution of dairy farms in the United States is characterized by two outstanding facts. First, there is huge variation in farm size from commercial dairy operations of less than 100 cows to commercial and less than two million pounds of milk per year to operations with 10,000 cows or more with 250 million pounds of milk per year (McDonald and Newton, 2014 and Sumner 2014).

Many studies investigate size distribution of dairy from many perspectives. Sumner and Wolf (2002 pointed out that even the measure of farm size is complicated as dairy farms that are more vertically integrated (such as by producing dairy feed on the farm or raising replacement heifers) may have fewer cows and less milk production, but have larger value added. Similarly, a farm with specialize milk output, such as organic milk may have fewer cows but produce more total revenue.

Drivers of farm size and change in size related to cost patterns scale economies and use of specialized or limited resources. Early work by Sumner and Leiby (1987), Chavas and Magand (1988) and Zepeda (1995) discussed dairy farm growth and size distribution dynamics, and especially how human capital of the operator affects choices of size. Among the main concerns has been the fate of small dairy farms (defined in several ways) as explored explicitly in Tauer and Mishrab (2006) and Nehring et al, (2009). Wolf and Sumner (2001) showed how data up to that time was not consistent with the idea that the middle sized dairy farms were disappearing which would have led to a bimodal distribution with large dairy farms and small dairy farms with very few in the middle.

Table 1 provides data and calculations from sample of more than 100 California conventional dairy farms based on data from CDFA (2019b). Table 1 is in the spirit of MacDonald and Newton which was based on US dairies from the USDA samples. Table 1 shows declining cost per cwt through 2,000 cows with slightly higher costs in the highest cost category. In these data it is only the smallest category, less than 500 cows that has substantially higher costs, and given sample sizes and variations it is unlikely that the difference in the larger categories are significantly different from one another. Note also that the largest farms have higher revenue per cwt.

The category of costs not shown include feed (about half of the total, labor and replacement stock. We list depreciation and manure handling costs because those are most likely categories affected by regulations that require changes in manure management to reduce methane emissions.

Table 1. Average costs of milk production by size categories of conventional dairies in California.

	Conventional Dairies				
Size Category	>2,000	1,500-1,999	1,000-1,499	500-999	<500
Milk Production (cwt) per Cow per Month	19.60	21.09	19.33	19.75	17.75
Total Cost per cwt of Milk	$15.88	$15.43	$16.00	$16.03	$17.81
Operating Costs[1]	$2.99	$2.89	$3.28	$3.20	$3.59
Depreciation	$0.329	$0.267	$0.244	$0.340	$0.388
Bedding and Manure Haul	$0.040	$0.108	$0.079	$0.082	$0.141
Revenue per cwt of Milk	$16.93	$16.27	$16.36	$16.39	$16.86

Note: Values represent weighted averages using monthly milk production of each reporting dairy. [1]Operating costs include utilities, supplies, veterinary services, outside services, repairs and maintenance, miscellaneous, fuel and oil, interest, taxes and insurance, and depreciation, and bedding and manure haul

Strategies for Manure Management

Five major strategies that have been suggested and investigated to reduce methane emissions coming from handling manure (Lee and Sumner 2019 and CDFA 2017.

1. More pasture-based management includes both conversion of a non-pasture dairy or livestock operation to pasture-based management and/or increasing the amount of time livestock spend at pasture at an existing pasture operation. In California, pasture-based dairy farming occurs only in the North Coast region because of the abundance of precipitation and, therefore, pasture forage and because the land is often not suitable for intensive cropping. When winegrapes compete for pasture land in this region the land is almost always converted to grapes. Pasture-based dairy farming has not been economically feasible where irrigation water is limited and expensive.

2. Alternative manure treatment and storage practices including the installation of a compost bedded barn that composts manure or the installation of slatted floor pit storage manure collection that must be cleaned out at least monthly. Neither of these are subject to investigation in California.

3. Separation of manure solids prior to entry into an anaerobic environment (e.g. lagoon, settling pond, settling basin) to reduce anaerobic decomposition. A few methods of separating solids are the most common techniques.

a. Ponds to allow water evaporation from manure, which can be effective in dry climates or times of the year. A limit is large space for a pond to allow quick dehydration.

b. Dehydration using energy to heat and remove moisture from manure, but high initial costs and costly energy requirements limit its use.

c. Coagulation Flocculation, a relatively new technique for manure management, uses chemicals to aggregate suspended solids (coagulation) to form larger "flocs" that can be separated from the liquid.

4. Conversion from a flush to dry manure collection system using vacuum machines or scrape the surface with the help of a tractor or a similar machinery. These systems then need to use some further drying of the manure, either with direct or indirect solar or other energy source.

Numbers 2, 3 and 4 are considered the techniques used in funding under the Alternative Manure Management Program in California

5. Using anaerobic digestion with a covered lagoon to further process of methane into an energy source. We consider digesters, alternative manure management and pasture systems. We start with pasture which is most associated with organic dairies in California.

Size relationships and Manure Management on Pasture-based Organic Dairies

Dairies producing USDA-certified organic milk must provide grazing. And, since pasture grazing is one of the strategies to minimize methane emissions from manure organic dairies have are a step ahead in complying with new California GHG regulations for manure handling.

However, after twenty years of expansion, organic milk still represents only a small share milk produced in California. In 2008, organic milk production was 845 million pounds, or 2.1% of the total milk produced in the state. After almost a decade, organic milk shares 2.3% of the total milk produced in the state (or approximately 915 million pounds of organic milk in 2017). Table 2 shows the 2017 production share. The share of cows is a bit larger, 3.4%, and given the small production of organic dairies number of organic farms comprises 9.5% or all dairy farms in California.

Table 2 also shows comparison with of organic with conventional dairies in 2017. The annual milk production per cow of organic (pasture-based) dairies is 16,103 pounds annually compared to 23,664 pounds of milk on conventional dairy farms, that is only 68% of annual milk production per cow of conventional dairies. The average herd size of organic dairies is substantially lower than conventional operations. In 2017, the average herd size (milking and dry cows) in organic farms was 474 animals (408 milking cows), while herd size was 2,968 (2,587 milking cows) in conventional dairies (Table 2).

Table 2. Production of Organic Milk, Share of California Milk and Comparison with Conventional Dairies, 2017

	2017
	Share of California dairy industry
Total Milk Production (Pounds)	2.3%
Number of Cows	3.4%
Number of Dairies	9.5%
	Organic Compared to Conventional
Annual Milk per Cow per Year (Pounds)	68%
Average Herd Size	16%

Source: California Department of Food and Agriculture dairy division.

The CDFA has collected data on farm costs and returns of a sample of more than 100 dairy farms for many years. The sample includes dairy farms located in four major milk production regions in California: North Coast, North Valley, South Valley, and Southern California. The sample includes organic dairies as well as conventional dairies (CDFA 2018).

Table 3 summarizes milk production, costs and revenue in the sample of conventional and organic dairies. We note that almost all the conventional dairies are in the San Joaquin Valley and almost all the organic dairies are in the North Coast region. Milk production per cow is substantially lower in organic farms; while the price received per pound of organic milk almost double the price received per pound of conventional milk.

Feed cost per cow per month, the major production cost, is much higher for organic dairies. Feed is also a higher share of total cost for organic dairies (61% of total cost) than conventional dairies (54% of total cost). Average production cost per cwt of milk was $27.74 for organic dairies compared to $15.90 for conventional dairies. However, revenue per cwt is much higher for organic dairies than in conventional dairies (Table 3). Net revenue per cwt is $3.10/cwt for the organic herds compared to $0.81/cwt for conventional herds. For the average herd size and production per cow, the net revenue is $496,000 for the conventional herd is compared to $204,000 for the organic herd.

Notice that manure management operating costs are only about $0.06 per cwt on conventional dairies and $0.13 per cwt on organic dairies. This also makes clear that organic dairies are not purely pasture-based for manure handling and must also manage manure in barns and milking parlors.

Table 3. Costs and Returns, Organic and Conventional Dairies in 2017

	Conventional Dairies	Organic Dairies
Number of Reporting Farms	96	13[1]
Number of Milking Cows	2,587	408
Milk (cwt) Production Per Cow Per Month	19.72	13.42
1. Feed	$8.61	$16.92
2. Labor	$1.85	$3.80
3. Replacement	$1.83	$2.14
4. Operating[2]	$3.05	$4.62
4.1. Depreciation	$0.31	$0.62
4.2. Bedding and Manure Haul	$0.061	$0.130
5. Marketing	$0.55	$0.25
Total Dairy Production Costs per cwt of Milk	$15.90	$27.74
Total Milk Production cwt per year	612,188	65,704
Revenue per cwt of Milk	$16.71	$30.84
Revenue total	10,229,661	$2,026,311
Total Cost $ per year	9,733,789	$1,822,638
Net Revenue per year	$495,872	$203,673

Note: Values represent weighted averages using monthly milk production of each reporting dairy. There were 11 organic farms in North Coast, and 2 in North Valley that reported information during 2017. Operating costs include utilities, supplies, veterinary services, outside services, repairs and maintenance, miscellaneous, fuel and oil, interest, taxes and insurance, and depreciation, and bedding and manure haul.

Manure Handling to reduce methane on conventional dairies in the Central Valley and Size Relationships

In the major dairy region of California there are few if any organic dairies. Manure handling has been typically entailed flush into an open lagoon. We consider conversion to digesters and conversion to manure management that reduces alternatives to digesters.

Digester Projects

The construction of an anaerobic digester incurs a large capital investment, which includes cost components that are fixed or do not vary proportionally with amount of material digested. Some operating and regulatory compliance costs are also not proportional to scale. For example, one-time or annual permit fees or utility interconnection fees are mostly invariant to amount of material digested or amount of energy generated. The possibility of economies of scale in anaerobic digester projects was suggested as early as 2002, and almost all studies on dairy digesters verify that per unit costs decline with the scale of the project.

Much attention has been paid to identifying the minimum threshold dairy herd size that makes a digester project viable. The size of between 500 and 1,000 cows was widely accepted in the US literature (based on the literature reviewed in Lee and Sumner 2014). Recent California investigations suggest scale economies for larger sizes for digesters.

Centralized digester systems are explicitly designed to gain economies in digester operation by using the manure from a cluster of dairy farms. A cluster of dairy farms may be connected through a manure distribution system to a centralized digester. The four main benefits of centralized systems are economies of scale, better leverage in marketing of energy output, additional financing opportunities, and third-party management. The review in Lee and Sumner (2014) summarized scale economies from the early literature. Lee and Sumner (2019 and Kafka et al. (2017) deal with the current situation in California as does the technical analysis in Arndt et. al 2018.

Table 4 shows a summary of economic data from recently funded digester projects under the CDFA program. The cost of implementation of a digester project has been about $5.0 million per dairy project with about 37% of project cost subsidized. The total annualized cost of the capital costs of the digester averages about $434,000 per dairy, using an interest rate of 6% over a 20-year period. Annual operation and maintenance costs are about $588,000.

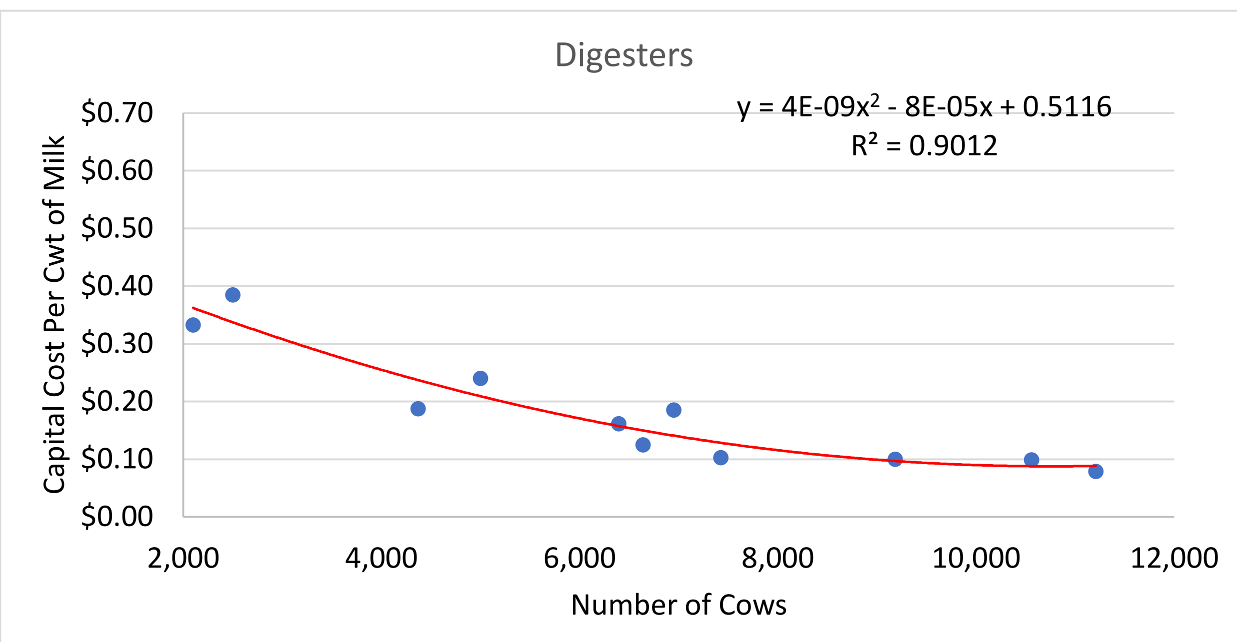
Figure 1 plots the capital costs per cwt of milk production of the dairy for each project against the estimated number of cows. To the extent that these projects are representative of what is available to the industry we may learn something about scale economies and cost/size relationships. We note that the project descriptions vary and may include somewhat different sets of costs. Moreover, number of cows and milk production are estimates and projections not historical data. Given those caveats the clear downward slope of the per unit costs is evidence consistent with scale economies.

Table 4. Capital and annual operational and maintenance (OM) costs of digesters from a sample of 11 applications that were funded granted by CDFA

	Digesters for operations between about 2,000 and 11,000 cows
Number	14
	Averages
Capital Cost ('000)	$5,018
Gov. subsidy ('000)	$1,832
Share Funded	37%
Annualized Capital Cost ('000)	$437
Annual OM Costs ('000)	$588
Total Project Cost per cwt of milk production*	$1.22

Source: CDFA funded digester projects. CDFA 2019. Estimated production from cow numbers.

Figure 1: Capital Cost of Digesters (for 11 funded California projects) per Hundredweight of Milk Produced Versus the Size



Authors construction from data provided by CDFA and other sources and CDFA cost feedbacks.

Alternative manure management projects

California initiated the Alternative Manure Management Program (AMMP) in part over concern that digesters would be less appropriate for relatively small dairy operations. The concern is that use of large scale and relatively indivisible technology would be the most cost effect ways to comply with the new methane emission standards.

The capital cost of implementation of an alternative manure management project is, on average, about $628,000 per dairy, but the cost for the dairy is about $84,000 after including the subsidy from CDFA. Including an interest rate of 6% over a 20-year period, the annualized cost of an alternative manure management project is about $58,000 per dairy. If we consider a dairy farm with 1,300 cows that produce around of 225 cwt of milk per cow per year, the cost of an alternative manure management project per cwt of milk is about $0.19. The annualized capital cost of an alternative manure management project corresponds to a 1% of the production cost on the dairy.

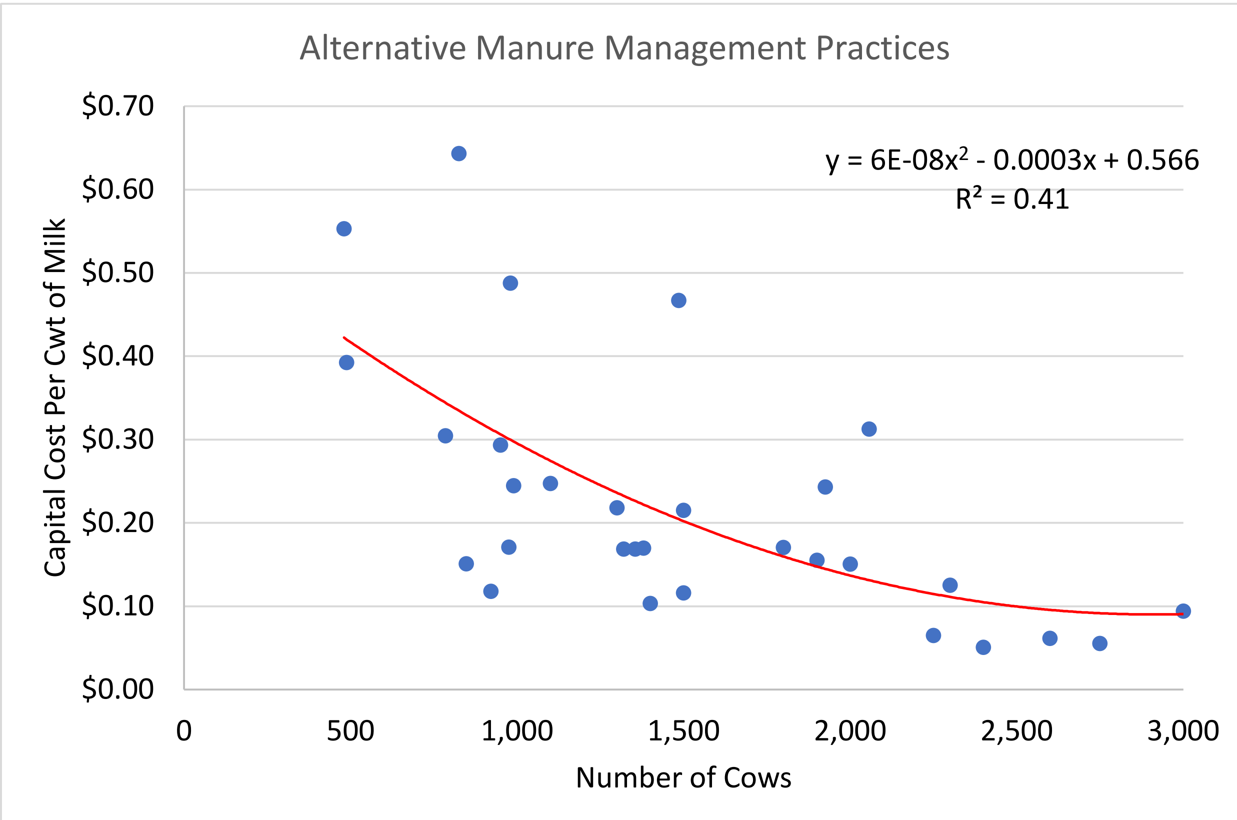
Table 5 summarizes data for alternative manure management projects funded by the AMMP, by number of cows. We find that that the cost per project falls as a ratio of milk production or number of cows. On an annual cost basis, the larger the herd size the smaller the cost per cwt (Figure 2). But these data must be interpreted with some care because of the great differences in technologies and what the projects entail.

Table 5. Capital and annual operational and maintenance (OM) costs of AMMP projects from a sample of 34 applications that were funded granted by CDFA

	Alternative Manure Management Practice				
Size Category (cows)	>2000	1500-1999	1000-1499	500-999	<500
Number	11	5	7	8	3
Capital Cost (‘000)	$561	$780	$721	$641	$378
Share Funded	82%	87%	81%	80%	95%
Annualized Capital Cost (‘000)	$49	$68	$63	$56	$33
Annual OM Costs	$2,934	$4,078	$3,774	$3,353	$1,980
Total costs per cwt of Milk	$0.06	$0.18	$0.27	$0.39	$0.56

Note: These data include some projects that may not be funding the whole investment in manure management on the dairy and includes a wide variety of technologies. It includes three project not included in Figure 2 because the data seemed inappropriate for the size cost relationship.

Figure 2: Capital Cost of Alternative Manure Management Practice per Hundredweight of Milk Produced Versus the Size of Conventional Dairies in California



Final remarks

A main issue for size distributions of dairy farms is how technology and capital used may vary across sizes. Meeting manure handling mandates for methane emissions is management intensive and may be low-cost for very small pasture-based farms. Optimally meeting mandates may be capital and management intensive and expensive for large dairies that invest in separate or joint methane centralized digesters to produce pipeline ready methane for vehicle fuels. Despite capital costs of centralized digesters are shared, at least in part, by neighboring dairies that are part of a cluster, it is higher than the establishment of the entire herd of a typical farm from San Joaquin Valley in California. Further, the economic feasibility of these projects is subject to policy risk. For example, Lee and Sumner (2018) show that price fluctuations of credits have a major impact on the net present value in centralized digester projects. In turn, for moderately sized dairies too large for pasture operations, methane reduction options may entail substantial scale economies that put them at a commercial disadvantage.

Preliminary results indicate that the cost shared attributed to scrape corrals and hauling manure in small dairies (i.e., less than 500 cows) is 4.21% of all operational costs being 2.6 times higher than in large dairies (i.e., more than 2,000 cows). The inclusion of drying or composting the collected manure result in an increase of operational cost plus the rise of the annual flow of capital cost. These increments are proportionally bigger in small dairies compared to large dairies. An important finding is that conventional moderate sized dairy farms seem more sensitive to these regulations as their fixed production costs may significantly increase relative to the level of methane mitigation reduction.

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