

Comparing greenhouse gas emissions of dairy systems

cias research brief **101**

Center for Integrated Agricultural Systems • UW-Madison College of Agricultural and Life Sciences

April 2019

Greenhouse gas emissions from livestock farms have received a lot of attention in recent years. Some studies have concluded that intensive confinement systems have the lowest greenhouse gas emissions per pound of milk or meat produced, while other studies have found that grass-based livestock farms have the lowest net greenhouse gas emissions.

Calculating greenhouse gas emissions of different farming systems is complex, and the results of each study depend on the geographic area considered and specific assumptions about management. When researchers at UW-Madison compared greenhouse gas emissions of several different dairy farming systems in Wisconsin, they found that emissions were broadly similar between grazing and confinement dairies. Most studies comparing greenhouse gas emissions of conventional and grass-based livestock systems do not examine the effect of management differences within each of those approaches. This study looked at the effect of different grain supplementation rates on emissions from grazing systems, and at the effect of adding an anaerobic manure digester on emissions from confinement dairies. The study showed that details of manure management, feeding strategies, and crop production decisions affect total greenhouse gas emissions more than whether or not a farm practices grazing.

In this model, the confinement system with the anaerobic digester resulted in the lowest overall emissions, primarily because the energy value of the methane produced in the digester reduced the need to burn fossil fuels for electricity generation. For all the other dairy farms, this model found that approaches balancing pasture intake and feed supplementation to optimize milk production resulted in the lowest greenhouse gas emissions per unit of milk produced.

The details of manure management and crop production affect greenhouse gas emissions from all types of dairy farms.

Background

In September 2010, the USDA NRCS Grazing Lands Conservation Initiative (GLCI) and the Wisconsin Department of Natural Resources partnered with the Green Cheese project at UW-Madison to model greenhouse gas emissions under different dairy production systems, and provide guidance on improving the sustainability of milk production. UW-Madison researchers Douglas Reinemann, Rebecca Larson, Horacio Aguirre-Villegas and Thais Passos-Fonseca from Biological Systems Engineering, and Victor Cabrera from Dairy Science modeled emissions from five grazing systems with varying levels of dry matter intake from pasture and grain supplementation, and two confinement systems (one with an anaerobic digester).



The grazing scenarios in this study differed in the levels of dry matter intake from pasture and feed supplementation.

Gas emissions modeled

The research team modeled the following greenhouse gas emissions over the course of a year:

- methane (CH₄) from ruminant digestion
- methane and nitrous oxide (N₂O) emissions from manure during collection and storage
- methane and nitrous oxide emissions from crop fields and pastures
- carbon dioxide (CO₂) emissions from on-farm energy use (tractor use, etc.)
- carbon dioxide emissions generated off farm for inputs such as fertilizers and pesticides

Emission levels of all gases were converted to CO₂ equivalents, which for any gas represents the amount of CO₂ that would have an equivalent global warming impact.

Model limits

No model can take all factors into account. This analysis ignored changes in carbon storage in soils. In other words, no credit was given for the potential for carbon sequestration in pastures, nor were emissions estimated for soil carbon loss from cropped fields. Furthermore, the model did not look at consumption and disposal of milk after it leaves a farm. It is also important to note that greenhouse gas emissions are only one aspect of a farm's environmental sustainability. Other measures of environmental performance, such as water quality and infiltration, soil health, biodiversity, and air quality were not addressed in this model.

Management factors

The key management factors the model considered were **dairy herd nutrition; manure handling**, including biogas generation and field application; and **crop production** for dairy feed and ethanol and biodiesel feedstock production. The researchers used databases and information from other research literature, and made their own calculations and estimates based on field data when Wisconsin or Midwest-specific life cycle inventory data were not available.

Model assumptions

Models rely on hypothetical farms, and the assumptions made about the farms in the model affect the results. The model made the following assumptions about the farm systems it compared:

- All the herds had similar cattle breeds and body weights.
- All the herds had a dry period of 62 days and a 14-month calving interval.
- All the farms raised all dairy heifers needed to maintain the herd size, and the adult replacement rate was equal in all seven systems.
- All the farms produced 22,046 pounds (10,000 kg) of milk per day at 3.1 percent protein and 3.7 percent fat. Since cows that rely more heavily on pasture than stored feeds tend to produce less milk than those fed more grain, the researchers increased the number of cattle in some pasture scenarios in order to reach the targeted level of production.

The key differences between the seven farm scenarios were how the cows were fed and how their manure was handled.

- In the two confinement scenarios, the cows were fed a standard total mixed dairy ration (TMR) year round.

- In the grazing scenarios, all cows were fed a standard TMR from October to April. From May through September, dry matter intake from pasture ranged from nine to 62 percent depending on the scenario. Supplementation in these scenarios ranged from 14 lbs/hd/day of corn up to 21.4 lbs/hd/day.
- All manure in the confined anaerobic digester (CAD) scenario was stored and processed in an anaerobic digester, which exported the methane generated from the manure to produce electricity. The manure produced by cows in confinement in the other six scenarios was stored in uncovered lagoons.
- For all scenarios, it was assumed that manure collected while the animals were confined was removed and spread on fields and pasture in April and October. Thus, for the grazing scenarios, one month's worth of manure was stored through the warm summer months.

Table 1 lays out the herd structure and diet assumptions for all seven scenarios. The grazing scenarios are designated by a G, and the two confinement scenarios are without an anaerobic digester (C) and with an anaerobic digester (CAD).

Table 1. Seven dairy farm scenarios used in analysis

	G1	G2	G3	G4	G5	C	CAD
Farm characteristics							
#milking cows	286	286	315	286	315	286	286
#growing heifers	161	161	176	161	176	173	173
#mature heifers and dry cows	66	66	70	66	70	83	83
Calving	Year round	Year round	Year round	Seasonal	Seasonal	Year round	Year round
Feed and milk during the grazing season (May to September*)							
% Dry matter intake (DMI) from pasture	9	49	54	56	62	0	0
Milk (per cow/day)	35 kg (77.2 lbs)	35 kg (77.2 lbs)	28 kg (61.7 lbs)	35 kg (77.2 lbs)	28 kg (61.7 lbs)	35 kg (77.2 lbs)	35 kg (77.2 lbs)
Diet (per cow/day)							
Intensively managed pasture	2 kg (4.4 lbs)	12 kg (26.4 lbs)	12 kg (26.4 lbs)	14 kg (30.8 lbs)	14 kg (30.8 lbs)	0	0
Mature legume silage	5 kg (11 lbs)	3 kg (6.6 lbs)	3 kg (6.6 lbs)	2 kg (4.4 lbs)	2 kg (4.4 lbs)	5 kg (11 lbs)	5 kg (11 lbs)
Corn silage	5 kg (11 lbs)	0	0	0	0	8 kg (17.6 lbs)	8 kg (17.6 lbs)
Corn grain	8.4 kg (18.5 lbs)	9.7 kg (21.4 lbs)	7.2 kg (15.9 lbs)	9 kg (19.8 lbs)	6.5 kg (14.3 lbs)	6.5 kg (14.3 lbs)	6.5 kg (14.3 lbs)
Soybean meal	2.4 kg (5.3 lbs)	0	0	0	0	2.5 kg (5.5 lbs)	2.5 kg (5.5 lbs)
Total DMI	22.8 kg (50.2 lbs)	24.7 kg (54.4 lbs)	22.2 kg (48.9 lbs)	25 kg (55.1 lbs)	22.5 kg (49.6 lbs)	21.9 kg (48.3 lbs)	21.9 kg (48.3 lbs)

*All scenarios were similar for the confined winter months

Greenhouse gas emissions

The model calculated greenhouse gas intensity, or greenhouse gas emissions per kilogram of fat- and protein-corrected milk (FPCM). For all scenarios, enteric emissions of CH_4 (methane) from ruminant digestion were the greatest source of greenhouse gas emissions (see the blue segments in Figure 1). Enteric CH_4 emissions were slightly lower for cows that consumed fresh pasture than for cows that only ate stored rations, resulting in lower enteric emissions per unit of fat- and protein-corrected milk (FPCM) during the grazing season from scenarios G1, G2 and G4 than from the confinement farms. However, because scenarios G3 and G5 required more cows to produce the same amount of milk as the other farms, these scenarios had higher enteric CH_4 emissions per unit of FPCM than confinement farms.

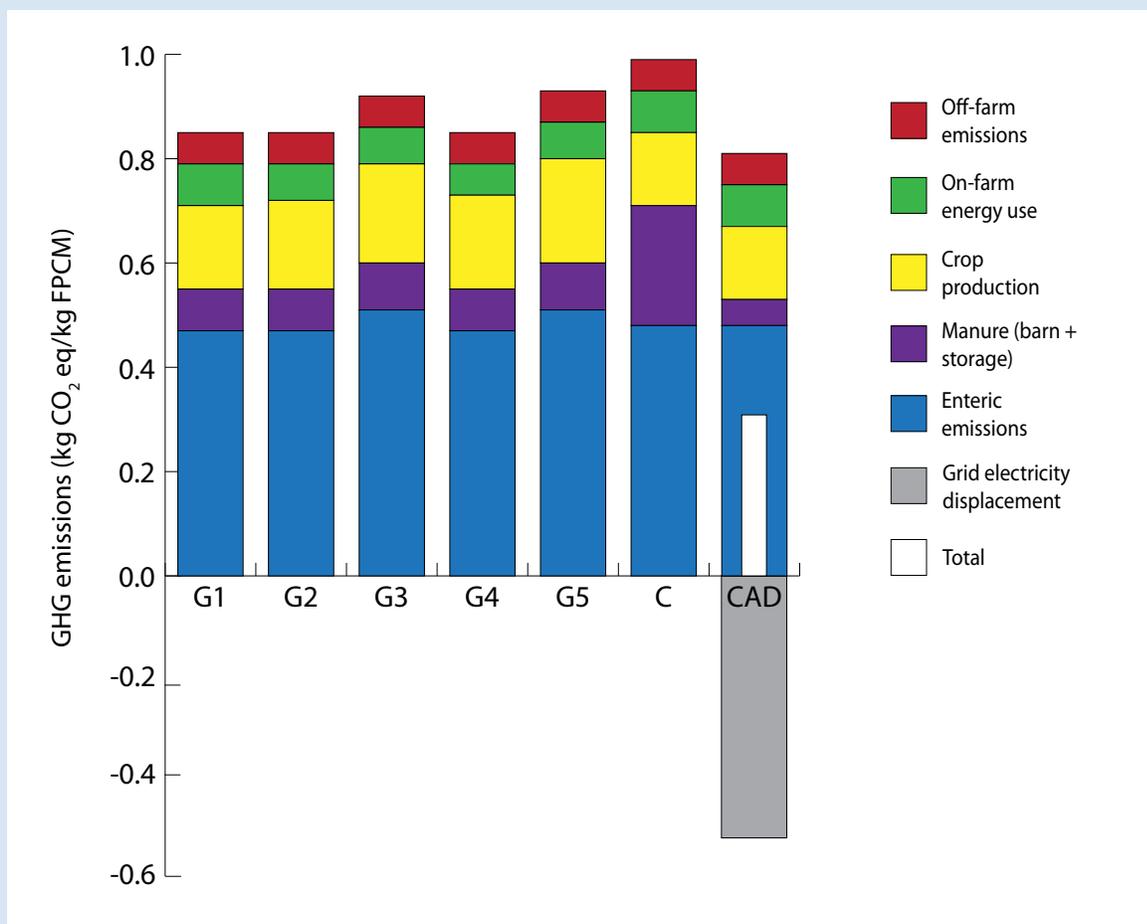
Emissions from crop production, including pasture, were the second largest source of greenhouse gases for most scenarios (see the yellow segments on Figure 1). Synthetic fertilizers and manure release N_2O and, to a lesser degree, CH_4 into the atmosphere when applied. The scenarios assumed that nitrogen, phosphorus and potassium were applied according to standard pasture and crop recommendations, prioritizing the use of dairy manure over purchased fertilizers. Manure that is deposited in buildings and stored on confinement farms volatilizes nitrogen as NH_3 (ammonia) during collection and storage, reducing the amount of nitrogen available to be emitted as N_2O after land application for crops. Fresh manure deposited on pasture has more nitrogen available to be emitted as N_2O . The model used International Panel on Climate Change estimates showing that nitrogen in fresh manure deposited by grazing cattle on pasture converts to N_2O at double the rate of synthetic nitrogen fertilizer. In addition, the scenarios assumed lower emissions of CH_4 from field application of stored manure than from manure deposited on pasture, because they assumed the CH_4 emissions from degradation of volatile solids in the manure had already occurred in storage. Thus, the modeling resulted in lower emissions of N_2O and CH_4 gases from crops on confinement farms than on grazing farms.



Emissions from crop production were the second largest source of greenhouse gases for most scenarios, after enteric emissions.

Stored manure (see the purple segments on Figure 1) was also a major source of greenhouse gas emissions in all but the CAD scenario, where CH_4 and N_2O emissions were reduced by the manure digestion processes. In all other scenarios, the manure was assumed to be scraped daily, contain 10 percent moisture chopped straw from bedding, and be stored in uncovered pits. Total solids content exceeded 10 percent, so the model assumed stored manure formed a natural crust and needed to be agitated before it was emptied from the pit. In all scenarios, manure was land applied in April and October. In these cases, six months' worth of stored manure was spread in April. In the grazing scenarios, one additional month's worth of manure from April was stored for six months until it was spread in October. N_2O emissions from stored and barn manure per unit of fat-corrected milk were lower on the grazing farms than on the confinement farms, so the total emissions from stored manure in the form of CH_4 and N_2O were higher on the confinement farm without the digester than any of the other farm scenarios. During storage, CH_4 emissions are highly dependent on temperature. Thus, the

Figure 1. Greenhouse gas emissions per kilogram of fat- and protein-corrected milk (FPCM) by scenario



model suggests that if the grazing farms were to spread April’s manure after the first cutting of hay in late May or early June instead of waiting until October, they could reduce their total greenhouse gas emissions by roughly eight to nine percent.

Other CO₂ greenhouse gas emissions in this model stemmed from on-farm and off-farm material and energy inputs (green and red segments, respectively, in Figure 1). Crop production was the sole source of on-farm material and energy emissions in this model, including lime applications and fossil fuel combustion. On-farm greenhouse gas emissions (in CO₂ equivalents) per unit of fat-corrected milk were slightly higher for cows in the confinement scenarios and the grazing scenario with higher levels of stored feed (G1) than for other grazing scenarios. This is due to the greater machinery use involved in producing larger amounts of stored feed and grains.

Off-farm emissions reflect the embedded emissions from materials including seeds and synthetic fertilizers, and energy inputs for milk, manure and cropping operations (for example, electricity used for milking machines). Off-farm emissions were similar per unit of milk produced for all of the scenarios.

Net results

The lowest net greenhouse gas emissions per unit of milk produced occurred in scenario CAD, the farm with the confined herd and on-farm anaerobic digester. The digester significantly reduced emissions of CH₄ and N₂O during manure storage. In addition, it replaced grid-based electricity with digester-produced electricity and so avoided the emissions resulting from burning fossil fuel to create electricity. However, the researchers note that anaerobic digesters, while promising, are expensive to install and manage and are not commonly installed on Wisconsin farms with fewer than 400 cows. If natural gas prices are low, it may not be economically feasible to install or operate an anaerobic digester with fewer than 1,000 cows and government subsidies. Additionally, there are environmental risks associated with spills from digesters due to the large amount of manure concentrated in one area.

Among all scenarios not involving an anaerobic digester, the lowest level of greenhouse gas emissions per unit of milk produced occurred in the three grazing scenarios with high rates of feed supplementation and milk production per cow: G2, with a high pasture intake level and a moderate level of stored feed; followed by G1, with a low pasture intake level and a high level of stored feed; and G4, with very high pasture intakes and a moderate level of stored feed. The highest net greenhouse gas emissions came from the confinement farm that does not have a manure digester (C).

Net energy intensity

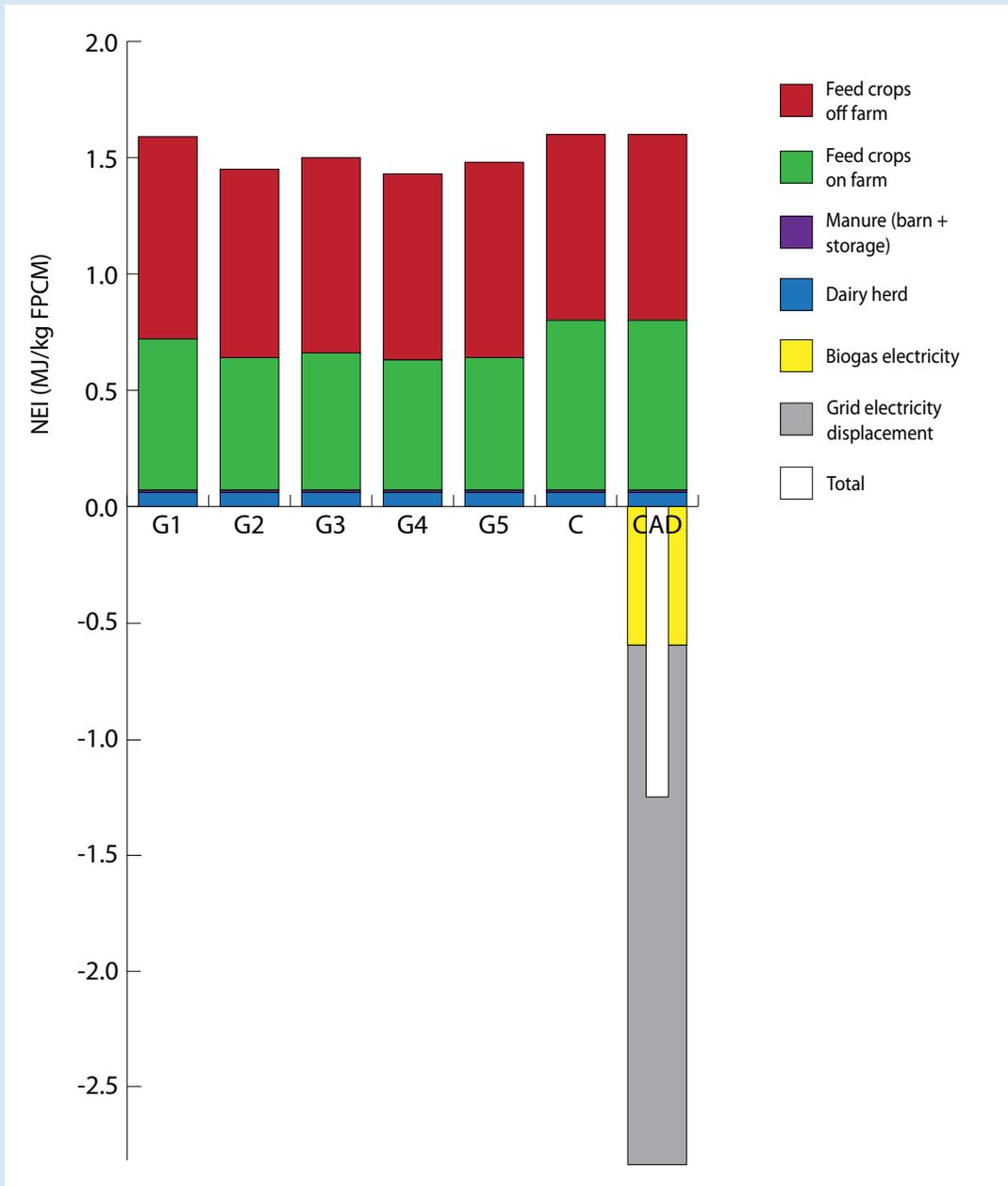
Another way to analyze the data generated by the models is by calculating Net Energy Intensity (NEI) (Figure 2). NEI is the difference between energy inputs and energy outputs and is a measurement of the amount of energy that is used directly on the farm as well as off farm in the manufacture of fertilizers, fuel and other inputs for dairy production. The production of feed crops off farm and on farm were the major contributors to NEI, highlighting the significant amount of energy that goes into manufacturing inputs (e.g., fertilizers, fuels). Allocated over the whole year, the CAD scenario had the lowest NEI. In this scenario, the energy needed for all aspects of farm production (both on and off farm) was more than offset by the combination of the energy produced by biogas and the grid energy it displaced. The amount of grid energy offset was over three times the amount of biogas produced, because all of the energy involved in grid production, including the mining and transporting of the coal or natural gas, was incorporated. For the remaining confinement and all grazing scenarios, NEI was the lowest in the G2 and G4 pasture scenarios, the ones combining high pasture intakes and high milk production. The most energy-intensive systems were C and G1, given their high levels of feed supplementation. Off-farm NEI in the pasture scenarios resulted in part from synthetic fertilizer use; incorporating more legumes in pastures could reduce both net energy intensity and associated greenhouse gas emissions in grazing systems.



Management details within pasture and confinement systems have an impact on greenhouse gas emissions.

“Overall, this study shows that management details within each system have a major impact on greenhouse gas emissions,” says Reinemann. “Large farms might reduce

Figure 2. Net Energy Intensity (NEI) of seven dairy farm scenarios



greenhouse gas emissions by installing a digester if they can afford the investment. Timing of manure application is important for grazing farms, and efficient use of fertilizers and other off-farm inputs can reduce the climate footprint of all farms.” This study also indicated that for farms that don’t include a manure digester, combining grazing with supplementation to maximize milk production produced the lowest greenhouse gas emissions per unit of fat- and protein-corrected milk.

The main reason the farm with the manure digester did best in this model was because it produced electricity that would otherwise have been generated by burning fossil fuels. However, the significant cost reduction in solar generation in the last decade, coupled with federal tax credits, makes it economically feasible for many types and sizes of farms to displace some greenhouse gas emissions from fossil fuel-derived electricity by installing solar photovoltaic systems.

This model did not address the soil carbon implications of different grazing intensities. Most studies show that healthy perennial pasture results in soil carbon equilibrium or gains, while annual crops result in a loss of soil carbon to the atmosphere. However, the amount of carbon storage or loss is determined by complex and incompletely understood interactions between soil type, climate, historic and current management, and other factors. Thus, while adding soil carbon to the model would likely reduce the overall climate footprint of grazing systems, management and site details would strongly influence how great that reduction would be.

“Farmers have to balance many factors when they decide how to manage their farm,” says Reinemann. “They are not going to switch from all grass to full confinement or vice versa just because of greenhouse gas emissions. This study shows that farmers can do something about climate change within the systems they already have. And in many cases, the practices that reduce greenhouse gas emissions, like careful use of nitrogen, good pasture management, and good cow nutrition, are also good for water quality and the farmer’s bottom line.”

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