Predicting greenhouse gas (GHG) emissions reduction in a dairy farm through dairy digester using a User Interface based analytical tool

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Introduction

- Cow manure managed in the open
- Emits greenhouse gases : methane, nitrous oxides, carbon dioxide, ozone, etc.
- Dairy methane emissions contribute up to 5 percent of the total carbon footprint in California

Fig. 1 Dairy Farm

Fig. 2 Conventional Manure Mgmt.

Anaerobic Digestion

Fig. 3 Covered Lagoon (Passive System)

Fig. 5 Plug Flow Digester

Fig. 4 Complete Mixed Digester

Fig. 6 Fixed Film Digester

Types of Manure Management Practices

- Pasture/Range Paddock
- Daily Spread Paddock
- Solid Storage
- Dry lot
- Liquid/Slurry
- Uncovered anaerobic lagoon
- Pit storage below animal confinements
- Anaerobic digester
- Cattle and Swine deep bedding
- Composting – (In-vessel, Static Pile, Intensive Window, Passive Window)
- Aerobic treatment

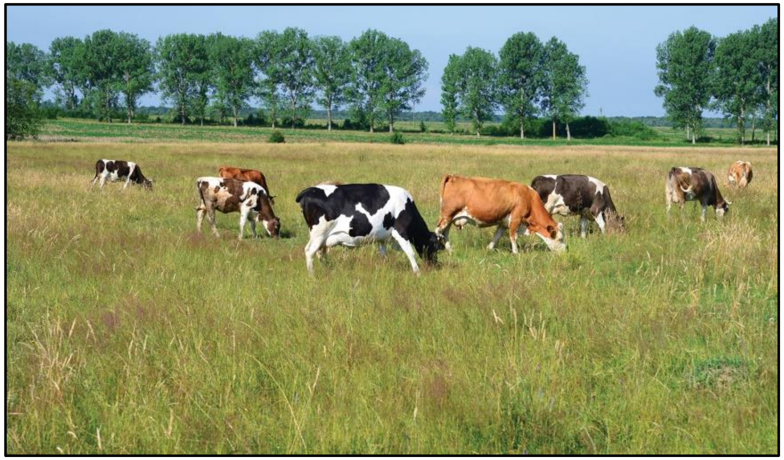

Fig.7 Pasture based management

Fig. 9 Composting

Fig. 8 Dry Lot

Fig. 10 Liquid/slurry manure mgmt.

Fig. 10 Aerobic Digestion

Fig. 11 Bedded Pack barns
(Cattle and Swine deep Bedding)

Fig. 10 Weeping Wall

Fig. 11 Bedded Pack barns
(Cattle and Swine deep Bedding)

Dairy Digester Research and Development Program

CDFA’s Dairy Digester Research and Development Program (DDRDP) provides financial assistance for the installation of dairy digesters in California, which will result in reduced greenhouse gas emissions

DDRDP Project Funding Eligibility

The proposed project should have a Biogas Control System which:

- Utilizes recovered biogas for electricity generation
- Recovers biogas and upgrades to transportation fuel
- Recovers biogas and upgrades to bio-methane (to replace natural gas)
- Recovers biogas for combustion in a boiler and the utilizes the thermal energy

DDRDP Calculator

Overview:

- Estimates the GHG emission reductions and co-benefits
- To provide a cost-benefit analysis of the proposed project
- Relies on CARB-developed emission factors.

Limitations:

1. No comparative study provided for analyzing different project inputs simultaneously
2. Excel worksheet is tedious and intimidating for first time users
3. Not user friendly (no help on processes and parameter values)

DDRDP Calculator

California Air Resources Board

Benefits Calculator Tool for the
Dairy Digester Research and Development Program

California Climate Investments

Cap and Trade Dollars at Work

Note to applicants:

A step-by-step user guide, including a project example, for this Benefits Calculator Tool is available here.

1. Biogas Control System (BCS)	Covered Lagoon		
2a. Primary Biogas Destruction Device	Upgrade to CNG/LNG fuel (onsite use)	15%	**2b. Percent of Biogas destroyed in primary destruction device (over 10 yrs)**
Will the fuel be used in a low NOx vehicle (0.02 g/bhp-hr or less)?	Yes		
2c. Secondary Biogas Destruction Device	Upgrade to biomethane for pipeline injection (remote use)	85%	**2d. Percent of Biogas destroyed in secondary destruction device (over 10 yrs)**
2e. If the raw biogas is trucked within a dairy cluster to a central biogas processing station, enter the round trip mileage and vehicle fuel type.	0		
2f. If the fuel will be trucked to an offsite fueling station, enter the round trip mileage and vehicle	0		

OBJECTIVES OF THE DEVELOPED TOOL

- To develop a basic GUI (Graphical User Interface) based software tool from the existing DDRDP quantification methodology.
- To make the GUI software more comprehendible and friendly to the user
- To provide simultaneous comparative results for different project inputs
- To provide a graphical study for the trend and sensitivity analysis (parameters: livestock population, county location, solid separation techniques, manure management practices, biogas destruction devices)

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Methodology

$$BE_{CH\,4,\,AS} = \sum (f_i \times VS_{avail\,AS\,,\,L\,,\,i} \times B_{0,\,l}) \times 0.68 \times 0.001 \times 25$$

$BE_{CH4,\,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems
$VS_{\deg AS\,,\,L\,,\,i}$ $[f_i \times VS_{avail\,AS,\,L,\,i}]$	=	Monthly volatile solids degraded in anaerobic manure storage/ treatment system 'AS', from the total available volatile solids for each livestock category 'L' in the month 'i'
$B_{0,\,l}$	=	Max. methane producing capacity of manure for a livestock
f_I	=	The van't Hoff-Arrhenius factor = % of VS that are biologically available for conversion to methane, depending on the monthly average temperature of the system/location.

0.68=Density of methane (1atm, 60^0F) (*kg/m³*) 25=Global warming potential of methane

Net GHG Emission Reductions	=	(Baseline methane(CH_4) and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit by utilizing methane)*

**Additional GHG benefit can be extracted by using the biogas for electricity generation, producing transportation fuel, offsetting fossil fuel like natural gas or diesel or by using the biogas for thermal energy generation in a boiler.*

Methodology

$$BE_{CH4,non-AS} = \sum_{s,l} (P_l \times MS_{non-AS,s,l} \times VS_l \times 365.25 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

MCF= Methane Conversion Factor; **$BE_{CH4} = BE_{CH4AS} + BE_{CH4non\text{-}AS}$**

- Project Methane Emissions from BCS

$$PE_{CH4,\ BCDE} = BE_{CH4,\ AS} \times [(1/BCE) - BDE]$$

BCE = Biogas Collection Efficiency *BDE = Biogas Destruction Efficiency*

- Project Methane Emissions from BCS Effluent Pond

$$PE_{CH4,EP} = VS_{EP} \times 365 \times MCF_{EP} \times 0.68 \times 0.001 \times 25$$

- Project Methane Emissions from Non-Anaerobic Storage/ Treatment Systems

$$PE_{CH4,non-BCS} = \sum_{s,l} (P_l \times MS_{non-BCS,s,l} \times VS_l \times 365 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

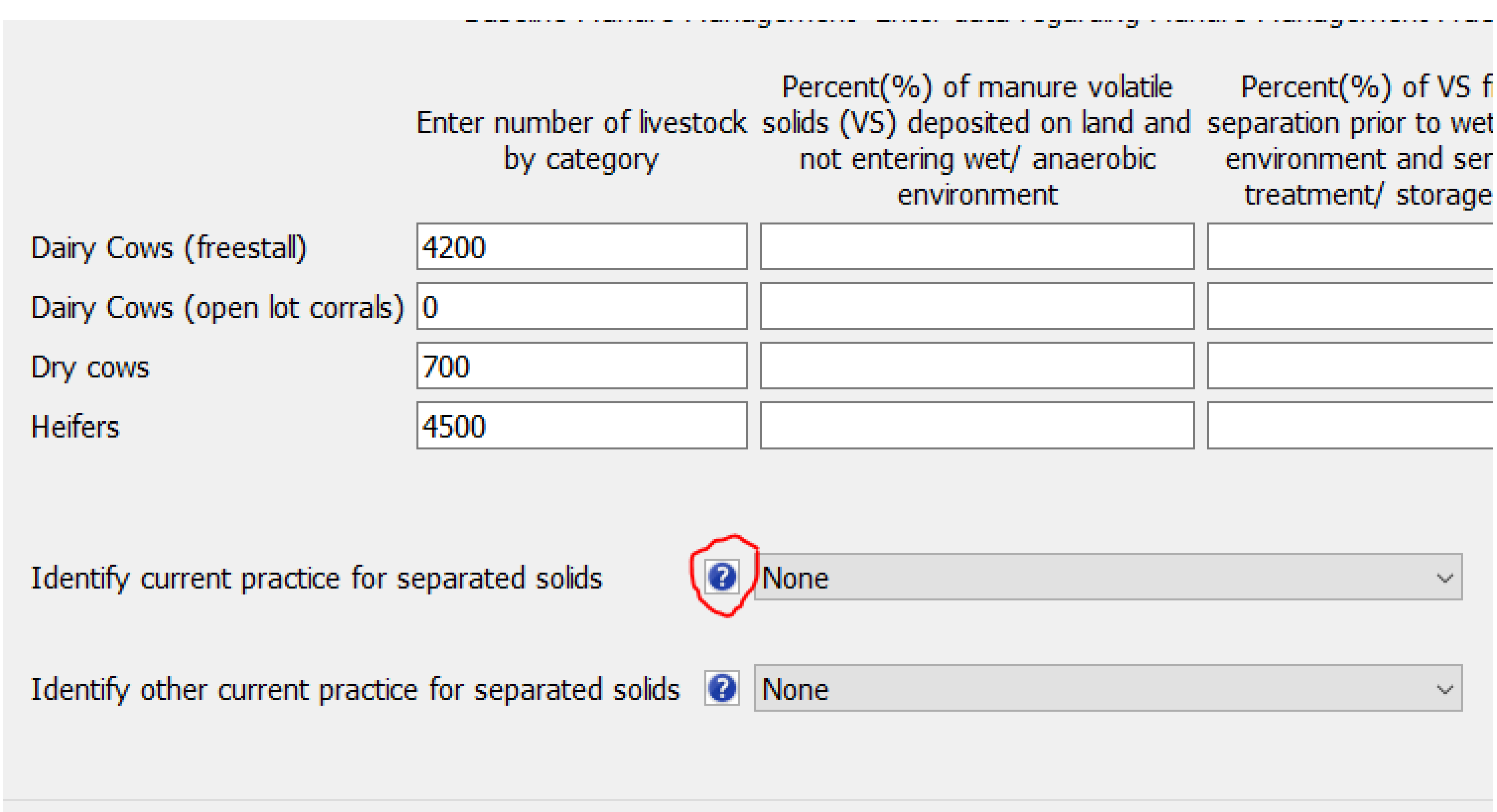
- Total Project Methane Emissions

$$PE_{CH4} = PE_{CH4,BCDE} + PE_{CH4,EP} + PE_{CH4,non-BCS}$$

SOFTWARE TOOL

- **GUI Designed in Qt Designer**
- **Coded in Python (PyQt5)**

Help Button to assist the user



Help Menu

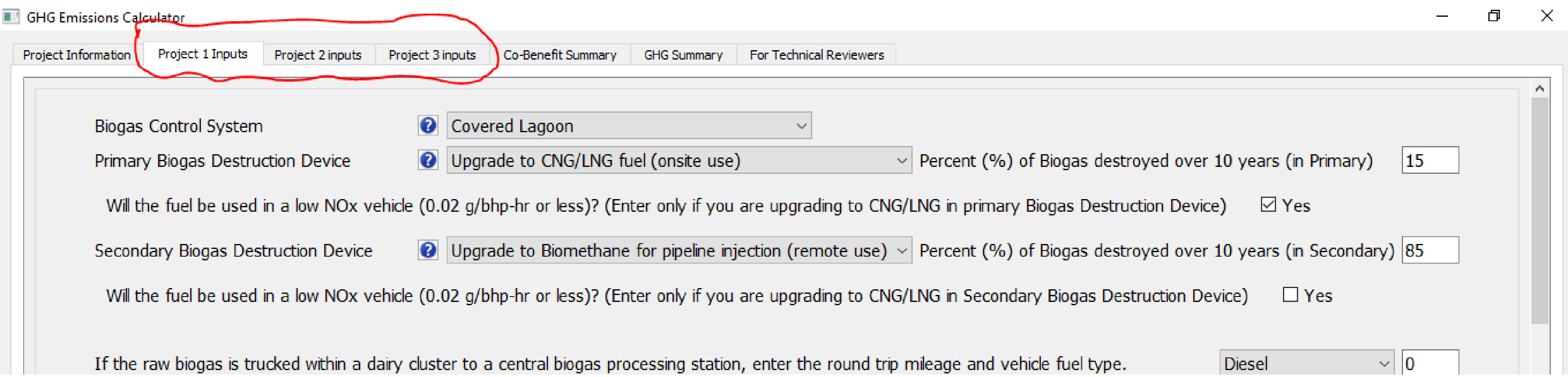
Help and Instructions

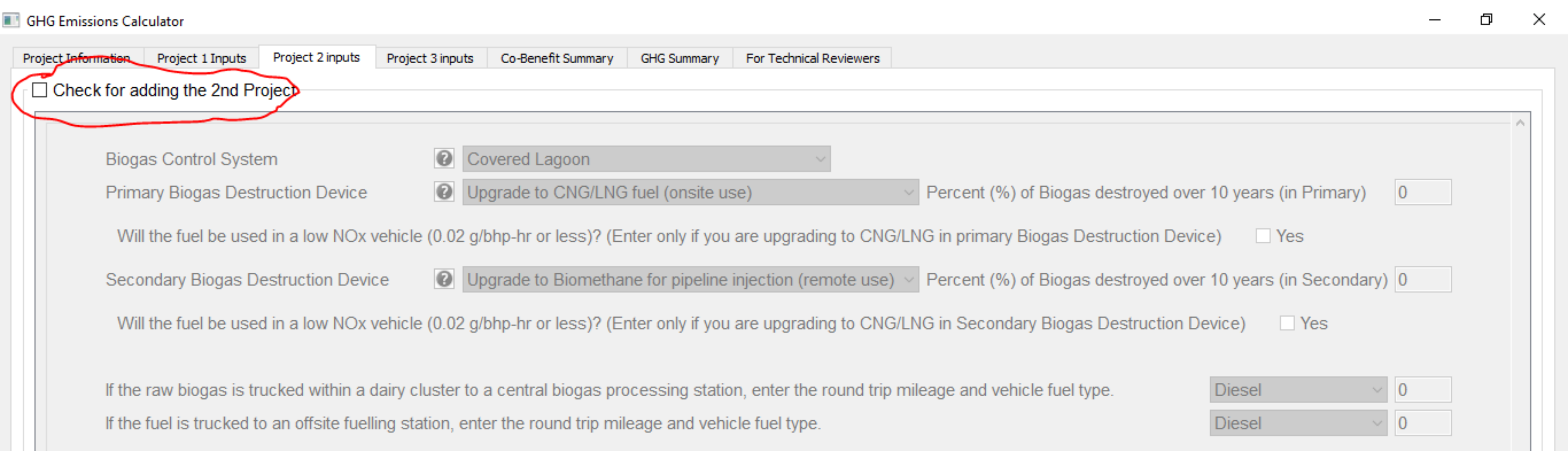
Biogas Destruction Device | Manure Management Practices

Pasture/Range Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily Spread Paddock	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion
Solid Storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting – In-vessel*	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.

**Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.*

Multiple Input tabs for comparing projects





Outputs for 3 different Project

GHG Emissions Calculator

Project Information | Project 1 Inputs | Project 2 inputs | Project 3 inputs | Co-Benefit Summary | GHG Summary | For Technical Reviewers

Total GHG reduction per total GGRF dollars requested over 10 years	{ GHG/(Total GGRF $) }	MTCO2e/$ requested	0.117	0.043	0.118
Portion of total GHG emission reductions attributable to the DDRDP funding	{ DDRDP GHG }	MTCO2e	233751	85576	236697
Total GHG reduction per $ DDRDP GGRF grant funds requested over 10 years	{ GHG/(DDRDP GGRF $) }	MTCO2e/$ requested	0.117	0.043	0.118
DDRDP funds requested per portion of GHG reductions attributable to DDRDP funding over 10 years	{ (DDRDP GGRF $)/(DDRDP GHG) }	$ requested / MTCO2e	8.56	23.37	8.45
Portion of the GHG emission reductions attributable to the GGRF funding from other California Climate Investments program(s), if applicable	{ GHG reductions attributable to other CCI programs }	MTCO2e	0	0	0

Table 2

			Project 1	Project 2	Project 3
Baseline CH4 emissions from anaerobic storage/treatment systems	{ BE_CH4 AS }	MTCO2e/yr	29022.57	10914.76	29022.57
Baseline CH4 emissions from non-anaerobic storage/treatment systems (including separated solids)	{ BE_CH4 NAS }	MTCO2e/yr	358.67	495.0	358.67
Baseline CO2 emissions associated with current manure mgmt practices	{ BE_CO2 }	MTCO2e/yr	0.0	0.0	0.0
Total Annual Baseline Emissions	{ BE_Total }	MTCO2e/yr	29381	11410	29381

GHG Emissions Calculator

Project Information | Project 1 Inputs | Project 2 inputs | Project 3 inputs | Co-Benefit Summary | GHG Summary | For Technical Reviewers

Fuel and Energy Co-Benefits

	Project 1		Project 2		Project 3	
Fossil fuel use reductions (onsite reductions) over 10 years	0.0	gallons*	0.0	gallons*	0.0	gallons*
Energy and fuel cost savings (onsite) over 10 years		dollars ($)		dollars ($)		dollars ($)
Renewable fuel generation over 10 years	1544866.81	gallons*	470011.55	gallons*	389392.2	gallons*
Renewable energy generation over 10 years	0	kWh	3910369.57	kWh	0	kWh

*diesel gallons equivalent

Air Pollutant Benefits

	Project 1				Project 2				Project 3		
	Local	Remote	Total		Local	Remote	Total		Local	Remote	Total
ROG Emission Reductions over 10 years	456740.0	0	456740.0	lbs	236335.0	81727	318061.0	lbs	457904.0	0	457904.0
NOx Emission Reductions over 10 years	-15714	0	-15714	lbs	-1956	513432	511476	lbs	749	0	749
PM2.5 Emission Reductions over 10 years	-1552	0	-1552	lbs	-844	128651	127807	lbs	0	0	0

Output values adjusted up to 2 decimal places

Conclusion

- **Advantages**:
    1) The calculations and indicators provide a holistic techno-financial overview of the project
    2) Comparative study between different manure management practices can be established using the tool.
    3) Easy to use tool with help guides for each input hence enabling the farm owners to understand the benefits due to various manure management practices
    4) The software can be easily upgraded (manually) for accommodating the changes in parameter values of emission factor, temperature etc.
- **Limitations**:
    1) Exact manure management practice practiced by the farmer may not be listed in the tool.
    2) The tool doesn't take into account the

Future Work

- Estimating the best practice for the fixed farm variables
- Providing a sensitivity analysis and a graphical study for in depth understanding of the effect of the variables

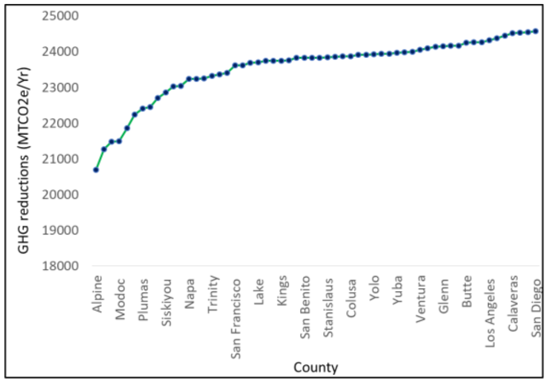


Fig 6. Effect of farm location on the total annual GHG reductions

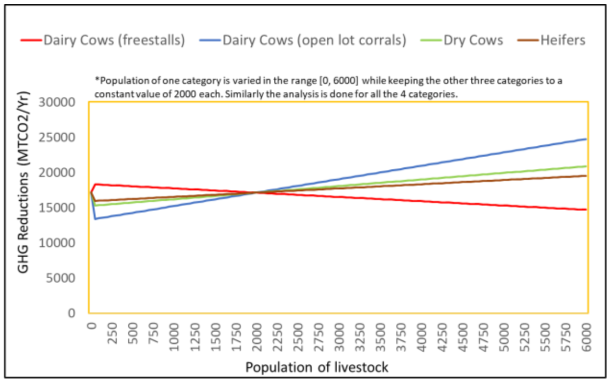


Fig 7. Effect of type of Cattle on total annal GHG reductions

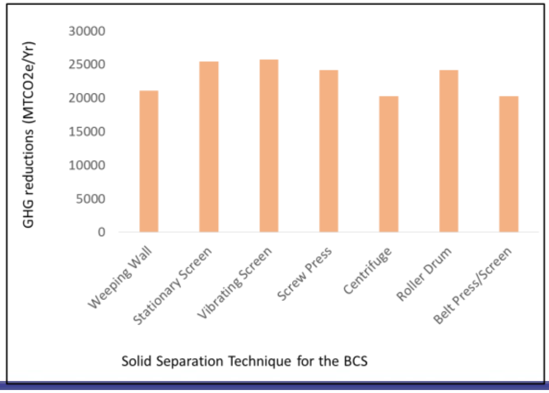


Fig 8. Effect of solid separation techniques on GHG reductions

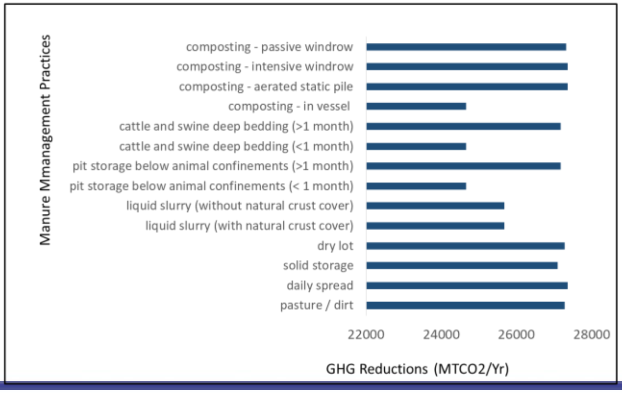


Fig 9. Effect of different manure management practices on GHG reductions

Future Work

- Making the software more user friendly by adding live suggestions
- Debugging the code for unwanted crashes during operation
- Making the GUI minimalistic by making the inputting process more structured
- Adding multiple number of projects for comparison at user’s behest

References

[1] Pandey P, Chiu C, Miao M, Wang Y, Settles M, del Rio NS, et al. (2018) 16S rRNA analysis of diversity of manure microbial community in dairy farm environment. PLoS ONE 13(1): e0190126.

[2] Pandey, Pramod & Biswas, Sagor & K Vaddella, Venkata & Soupir, Michelle. (2014). Escherichia coli persistence kinetics in dairy manure at moderate, mesophilic, and thermophilic temperatures under aerobic and anaerobic environments. Bioprocess and biosystems engineering. 38. 10.1007/s00449-014-1285-3.

[3] California Department of Food and Agriculture Dairy, Digester Research and Development Program (DDRDP), 2019. Available at: https://www.cdfa.ca.gov/oefi/ddrdp/

[4] California Air Resources Board (2019). Quantification Methodology for the California Department of Food and Dairy Digester Research and Development Program Available at: https://ww2.arb.ca.gov/resources/documents/cci-quantification-benefits-and-reporting-materials.