Achieving Carbon Neutrality through Renewable Energy Production and Carbon Sequestration: Case Study of a Farm and Environmental Education Center

Miguel J. Louis* and Uta Krogmann**

Department of Environmental Sciences, Rutgers University, NJ, USA

*Presenting author: ml1290@envsci.Rutgers.edu and **Corresponding author: krogmann@rutgers.edu

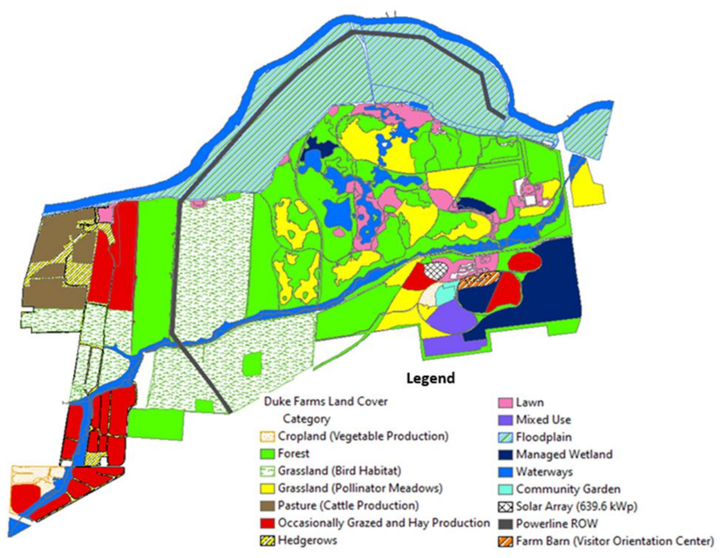
Introduction

- Carbon neutrality is the balance between anthropogenic greenhouse gas (GHG) emissions and removals, reported as carbon dioxide equivalents (CO_2-eq.) using global warming potentials.
- To mitigate climate change, anthropogenic GHG emissions need to be both, avoided or reduced, especially via decarbonization and increased energy efficiency, and removed by sequestering carbon in various carbon sinks.
- While there are various carbon footprint studies comparing measures to mitigate climate change, case studies evaluating both renewable energy and carbon sequestration are rare, especially with the latter mitigation based on measurements and modeling of carbon stocks.

Objectives

- Model a baseline carbon footprint of Duke Farms, a farm and environmental education center.
- Conduct scenario analyses of various additional carbon sequestration practices and renewable energy options to assess a path towards carbon neutrality.
- Conduct uncertainty analysis to assess effect of variability of input data (not completed yet).

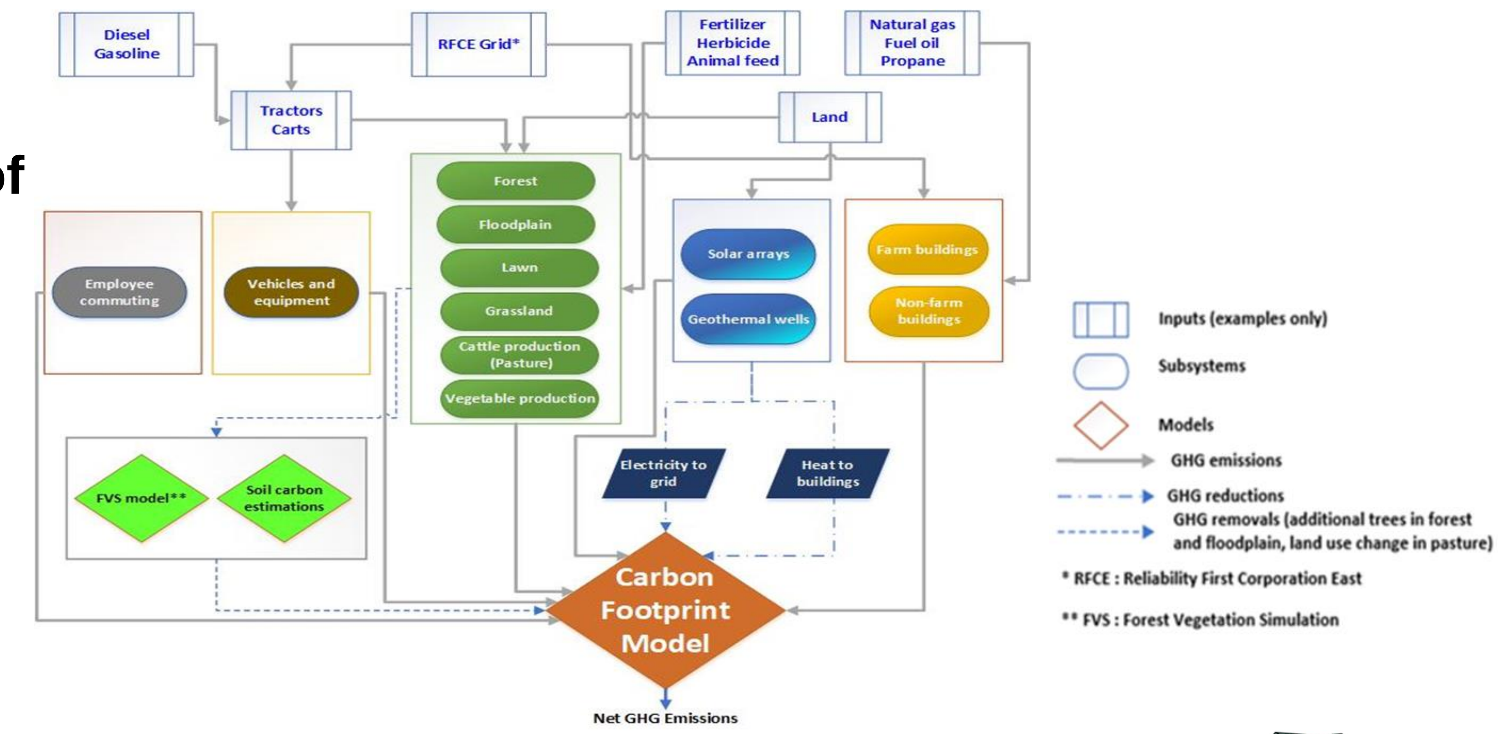
Study was part of a larger carbon mitigation and monitoring project (Giménez et al., 2024).



Land uses and land cover of Duke Farms in 2016 (total acreage: 1,110 ha)

Materials and Methods

Modeling framework of the carbon footprint

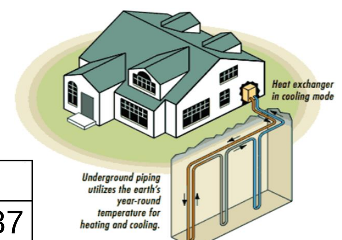


Energy consumption in buildings

Category	Type	Source	Unit	Quantity
Buildings	Farm operation	Electricity	kWh	112,434
		Natural Gas	Therms	1,778
		Fuel oil	US gallon	5,024
		Propane	US gallon	3,776
	Non-farm operation	Electricity	kWh	1,581,027
		Natural gas	Therms	71,775
		Fuel oil	US gallon	2,028
		Propane	US gallon	2,127

Renewable energy production

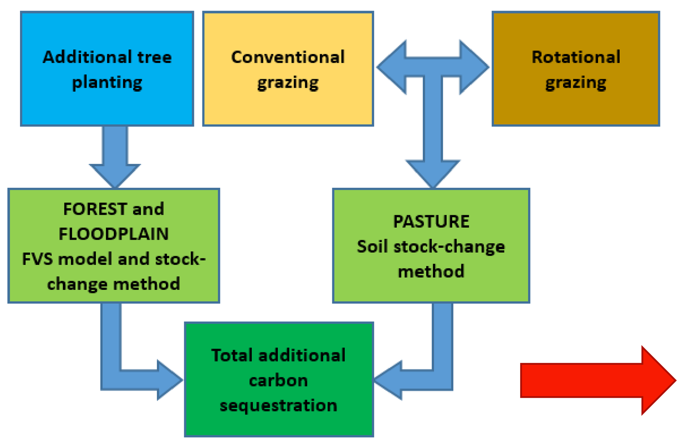
System	Product	Unit	Amount
Old PV system (2016)	Electricity	kWh	781,587
Geothermal (estimated)	Heat	MJ	1,012,347
New PV system (estimated)	Electricity	kWh	1,671,000
Battery storage (estimated)	Electricity storage	kWh	613, 000



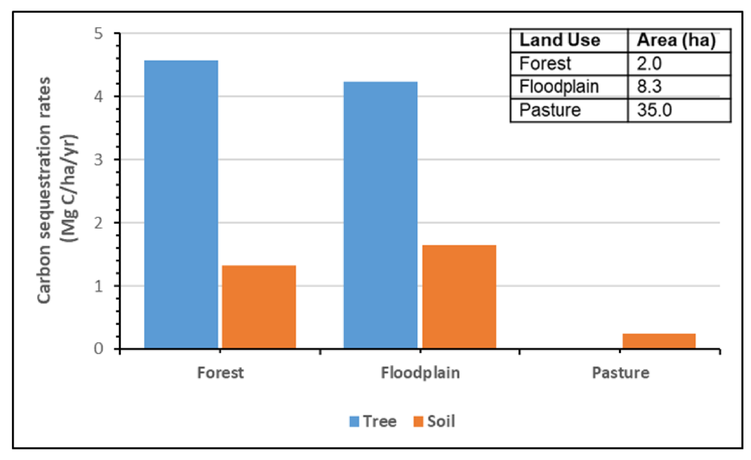
Geothermal system
Photo credit: igajpa.org

New PV system
Photo credit: Duke Farms

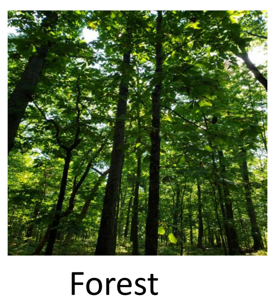
Additional (= beyond business-as-usual) carbon sequestration



Above and below ground biomass (live trees, roots and dead trees) modeled by FVS model (Dixon, 2002). Soil carbon based on sampling and carbon sequestration modeling at two different points in time



Carbon sequestration rates in tree and soil pools for various land uses (100 years assumed)



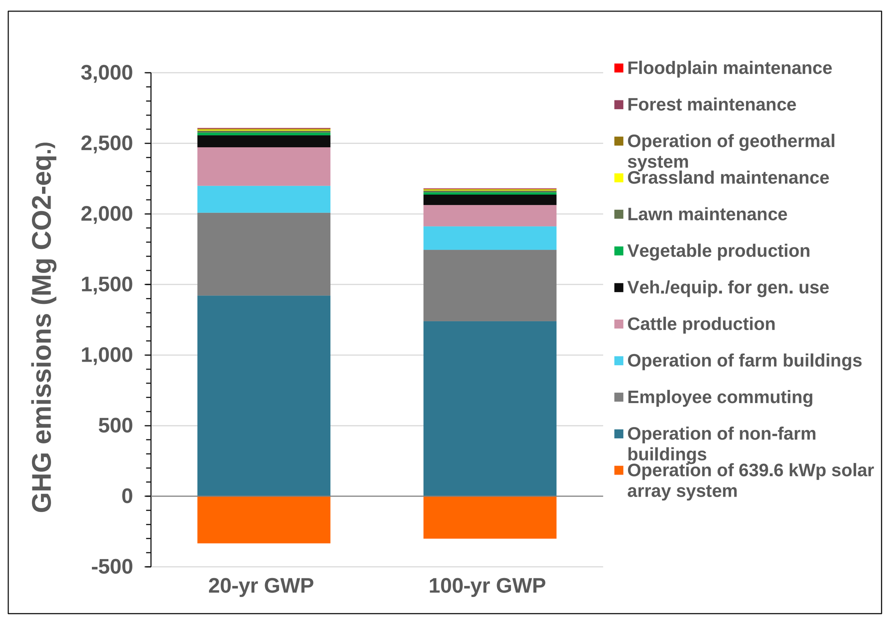
Forest

Pasture

Carbon footprint modeling

- Attributional carbon footprint for the year 2016 (baseline) according to ISO 14067 (ISO, 2018) and modeled in Simapro 9.6
- On-site data collection, missing data from the literature, and background data from Ecoinvent 3.9 database (Moreno et al., 2022)
- 100-year and 20-year global warming potentials (IPCC, 2021)

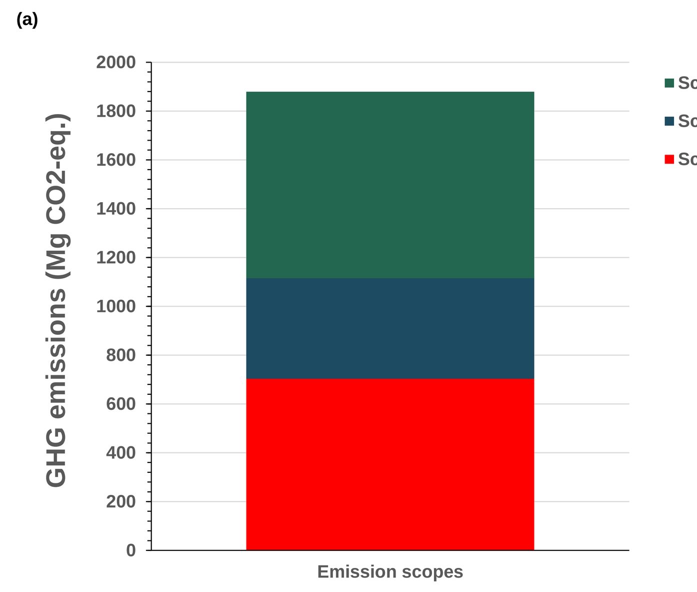
Results

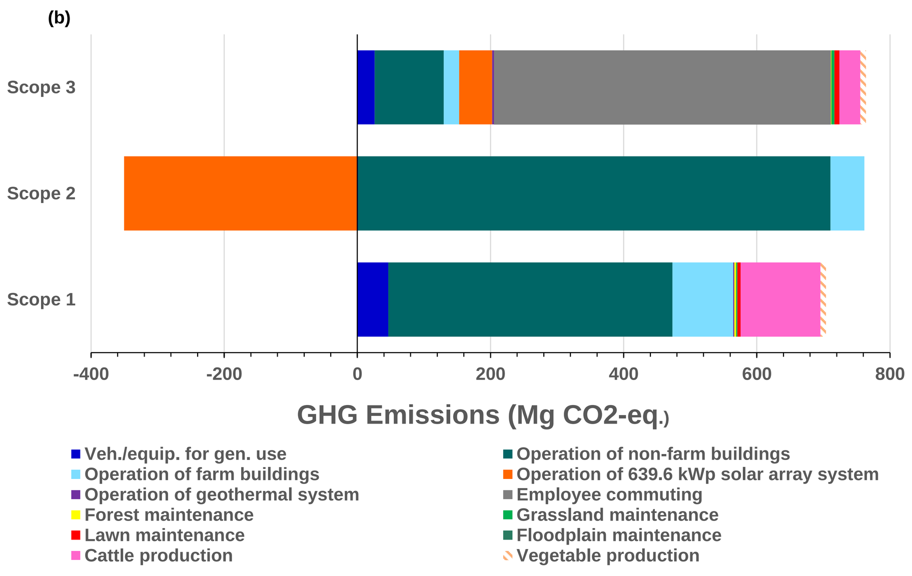


Subsystems	100-yr GWP (Mg CO2-eq.)	20-yr GWP (Mg CO2-eq.)
Floodplain maintenance	0.06	0.07
Forest maintenance	3.36	4.17
Operation of geothermal system	4.34	6.66
Grassland maintenance	6.49	7.43
Lawn maintenance	12.34	14.20
Vegetable production	16.69	18.57
Veh./equip. for gen. use	73.39	84.92
Cattle production	151.39	272.91
Operation of farm buildings	165.62	190.79
Employee commuting	505.88	587.24
Operation of non-farm buildings	1,240.10	1,421.55
Operation of 639.6 kWp solar array system	-300.65	-333.33
Total	1,878.99	2,275.18

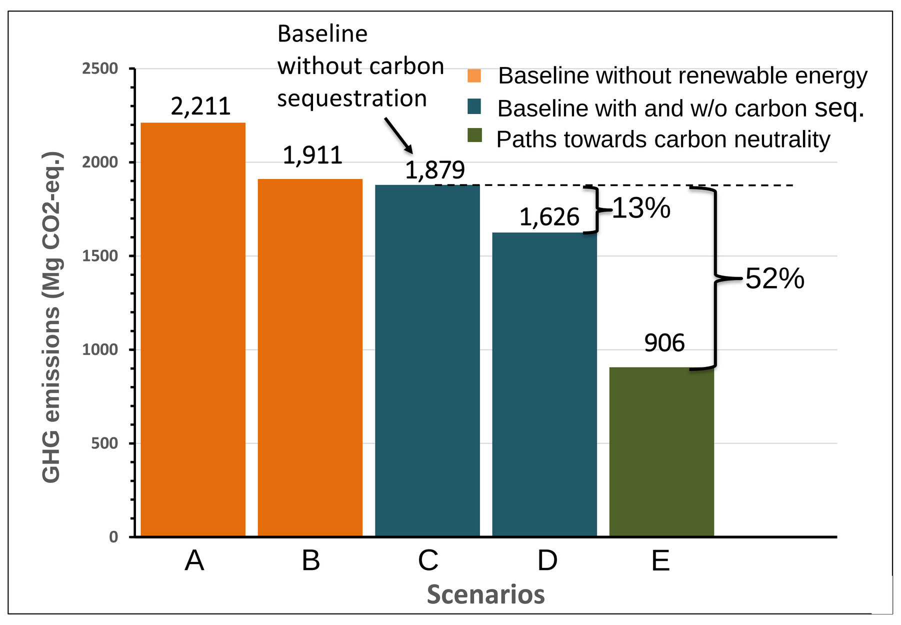
Baseline carbon footprint in 2016 without carbon sequestration

- Buildings and employee commuting > 90% of the baseline carbon footprint.
- Reduced heating in non-farm buildings due to geothermal energy (31,800 kg CO_2-eq).
- Credit for operation of solar array system included.





Emission scopes (a) and emission scopes by subsystem (b) of the baseline carbon footprint in 2016 without carbon sequestration for a 100-yr time horizon.



	Renewable energy			Additional carbon sequestration			Replace-ment of selected boilers with heat pumps
Scenarios	639.6 kWp solar system	1160 kWp solar system + batteries	Geothermal well system and heat pumps	Flood-plain	Forest	Pasture	
Baseline scenarios							
A							
B	✓						
C (Baseline w/o additional carbon sequestration)	✓		✓				
D (Baseline with additional carbon sequestration)	✓		✓	✓	✓	✓	
Scenarios towards carbon neutrality							
E	✓	✓	✓	✓	✓	✓	✓

Carbon footprint scenarios for a 100-yr time horizon

Discussion and Conclusions

- Building operation, employee commuting and cattle production contributed substantially to carbon footprint
- Climate neutrality not reached. However, study showed:
  - Renewable energy and carbon sequestration important with the former measure providing larger and more permanent reductions.
  - Carbon sequestration only to be included when beyond business-as-usual
  - Combining soil measurements and modeling promising in determining carbon sequestration rates compared to literature values commonly used in life cycle assessment.
- Recommendations
  - Further reducing GHG emissions in building subsystems.
  - Promoting less carbon-intensive cars and more working from home, if possible.
  - Planting additional trees in floodplain.
  - As most data are point estimates, performing uncertainty analysis to improve the robustness of the carbon footprint analysis.
  - Expanding the current carbon footprint analysis taking time into account as climate change impact associated with grid energy mixes and carbon sequestration vary in time.

References

- Dixon, G. E. (2002). Essential FVS: A user's guide to the Forest Vegetation Simulator. Department of Agriculture, Forest Service, Forest Management Service Center, Fort Collins, CO, USA, 226p.
- Gimenez, D., Kaplan, M., Krogmann, U., Lathrop, R., Murphy, S., and Schafer, K. (2024). Carbon mitigation research and monitoring program at Duke Farms. Rutgers, The State University of New Jersey, New Brunswick, NJ.
- Moreno Ruiz E., FitzGerald D., Bourgault G., Vadenbo C., Ioannidou D., Symeonidis A., Sonderegger T., Müller J., Valsasina L., Minas N., Baumann D. (2022). Documentation of changes implemented in the ecoinvent database v3.9. Ecoinvent Association, Zürich, Switzerland.
- IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.
- IPCC. (2021). Climate Change 2021: The Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.
- ISO. (2018). ISO 14067: Greenhouse gases–carbon footprint of products–requirements and guidelines for quantification; International Organization for Standardization, Geneva, Switzerland.

Acknowledgement

This study was funded through a grant by the Duke Farms Foundation and a Graduate Assistance in Areas of National Need (GAANN) fellowship from the U.S. Department of Education.