The Impact of Organic Farming on Greenhouse Gas Emission

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Introduction

Organic food has become a trend in recent years. Certified organic cropland and certified organic pastureland and rangeland have increased by 79% ang 90%, respectively, over the 2011-21 period (Skorbiansky, 2024). For produce to qualify as organic, it must meet certifications verifying that only approved substances were used on the soil for the 3 years prior to harvest (McEvoy, 2012). Data from Statista (2023) exhibits that the organic food market share of total food sales has expanded annually since 2000. In 2021, organic food sales accounted for about 3 percent of U.S farm receipts. In the U.S., fruits and vegetables account for the largest share of organic food sales, followed by dairy products, indicating that organic agriculture is one of the fastest growing sectors (USDA, 2018). Organic farming refers to sustainable farming systems that utilize ecologically based pest management and natural fertilizers derived largely from animal/plant waste and nitrogen-fixing cover crops (Adamchak, 2024). Despite higher prices, consumers choose organic options over conventional for reasons like personal health, wellness, and especially environmental impact (Apaolaza et al., 2018).

For governments and farmers, organic agriculture is the most financially viable tactic for battling climate change (Crowder & Reganold, 2015). According to a meta-analysis study comparing the financial performance of organic and conventional agriculture on a global scale across 14 countries on 5 continents over the last 40 years. The result showed that organic farming is not only environmentally sustainable, but also financially competitive when compared to conventional farming, despite a higher labor cost (Crowder & Reganold, 2015). The result is also consistent with a comparative economic analysis of different agricultural production systems, specifically focusing on conventional farming and organic farming. The result showed that organic farming provides environmental benefits at the local level, including reduced chemical runoff and pollution, increased biodiversity, and healthier soils and can be a cost-effective and sustainable option for farmers due to its lower input costs and ability to secure higher prices ((Durham & Mizik, 2021).

The question of whether organic farming substantially reduced greenhouse gas emission remains controversial (Drinkwater et al., 1998; Lee and Chloe' 2019). The present research investigates the relationship of organic farming and greenhouse gas emission in United States by utilizing data from 50 states over the period of 2000 to 2008. I expect that organic farming

methods, recognized for enhancing soil carbon sequestration and promoting energy efficiency, will significantly lower greenhouse gas emissions across various U.S. regions.

Literature Review

The impact of organic farming on environmental factors, especially the aspect of greenhouse gas (GHG) emissions, has gained substantial attention among researchers. A 2009 report by the United Nations (UN) Food and Agriculture Organization (FAO) states agriculture as a whole generates 13.5% of global GHG emissions but estimates organic farming could help mitigate up to 6 gigatons of carbon dioxide (CO_2) equivalent emissions annually (FAO, 2009).

Organic farming can reduce GHG emissions through two main mechanisms: soil carbon sequestration and more efficient energy use. Soil carbon sequestration is the natural process of capturing atmospheric carbon in the soil in the form of organic carbon (Cavigelli et al., 2013). Lal (2004) notes that soil carbon sequestration is an essential mechanism for mitigating climate change because it reduces carbon dioxide levels in the atmosphere. Most organic farming techniques aim to capture atmospheric carbon dioxide in soil organic matter through practices like applying compost, crop rotation, and minimal tillage (Cavigelli et al., 2013; Lal, 2004; Hernanz et al., 2009; Al-Kaisi & Licht, 2001).

Previous studies have compared the effects of organic and conventional farming practices on the ability of soil to sequester carbon. Sardiana (2021) in Bali assessed this potential, finding organic farm fields had 24.52% higher soil carbon storage compared to conventional fields. The research was conducted on ten fields of each type. Organic farming techniques increased soil organic carbon content, especially labile (easily decomposable) carbon, has the capability to improve soil fertility, reduce GHG emissions, and promote sustainable agriculture in Indonesia. These findings align with a 15-year comparative study by Drinkwater et al. (1998) on legume-based versus conventional farming systems, which finds organic practices enhance soil carbon sequestration. Despite having lower crop residue inputs, the organic systems increase soil carbon levels and retain more nitrogen with reduced leaching compared to conventional systems. The authors explain that these organic inputs are more readily decomposed by soil microorganisms, leading to humus formation – a stable organic matter that can sequester carbon over long periods (Drinkwater et al., 1998).

Additionally, organic farms tend to be more energy efficient by relying less on energy-intensive synthetic inputs like fertilizers and pesticides. Alonso and Guzmán (2010) examine the

energy consumption patterns of 78 organics versus conventional farms in Spain and find that organic farms demonstrate lower energy outputs on average compared to conventional farms, primarily due to reduced usage of energy-intensive inputs. Organic farms also exhibit lower consumption of non-renewable energy, aligning with the goals of enhancing agricultural energy sustainability. Michos et al. (2012) further evaluate energy flows and GHG gas emissions across conventional, integrated, and organic farming systems using a 12-year panel study of 16 farms in northern Greece. Their results show organic orchards have significantly lower average inputs (fertilizers, pesticides, fuel) compared to integrated and conventional systems (Michos et al. 2012). While energy outputs (harvested peach energy content) and efficiency varied, organic farming demonstrated lower outputs but also lower inputs overall. Importantly, organic systems resulted in significantly lower GHG emissions (CO_2, CH_4, N_2O) compared to integrated and conventional farming.

Prior studies on organic farming's impact on GHG emissions yield varying results, with studies highlighting different aspects of its environmental footprint. Lee and Chloe (2019) focus on Korean soybean cultivation and find conventional farming was more energy-efficient, though emissions were not significantly different between the two methods, contrasting with the results of Alonso & Guzman (2010) and Michos et al (2012). The study indicates that organic systems emit more CO_2 than the conventional ones, with lower organic yields but higher fuel and mulch film usage. Additionally, McGee (2014) uses 2000-2008 state-level data and finds a positive correlation between converting conventional to certified organic farmland and increasing agricultural greenhouse gas emissions, suggesting organic practices may not significantly reduce emissions compared to conventional. This increase was also observed in emissions intensity per acre.

With the aspect of carbon sequestration, Venkat (2012) conducts a lifecycle assessment of 12 California crops and find organic farming does not enhance soil carbon storage, resulting in 10.6% higher average greenhouse gas emissions than conventional methods after excluding walnut outliers. The study highlighted some contributors including lower yields, higher on-farm energy use, and extensive composting needs for some organic operations. Notably, they show emissions from synthetic fertilizer and pesticide production were not high enough to offset organic farming's higher emissions. These results differ from Sardian (2021) and Drinkwater et al (1998), raising the question of whether organic farming can enhance soil carbon storage.

Considering the diverse outcomes reported in previous studies, further investigation is essential to clarify the nature and extent of the connection between organic farming and GHG emissions. It's crucial to consider the limitations identified in earlier research, including potential moderating factors like energy consumption, long-term soil modifications, GDP, and precipitation patterns (Hansen et al., 2001; Carbonell-Bojollo et al., 2019), which could influence the dynamics between organic farming practices and emissions. Previous studies have often relied on cross-sectional data and limited sample sizes (Drinkwater et al., 1998, Venkat, 2012), introducing the risk of unaccounted errors. Additionally, many studies focus on particular locales, potentially ignoring variations in climate and soil quality across different regions. Thus, using panel data is needed for a deeper understanding of the relationship between organic farming and GHG emissions. In this study, I analyze panel data detailing gas emissions and certified organic farming activities across all 50 states in the United States from 2000 to 2008. I anticipate that organic farming methods, recognized for enhancing soil carbon sequestration and promoting energy efficiency, significantly reduces greenhouse gas emissions across various U.S. regions.

Data and Methods

In this paper, I use data on total GHG emission (measured in million metric tons of carbon dioxide equivalent), emissions from energy-related activities (measured in million metric tons of carbon dioxide equivalent), state GDP (millions of US dollars) and population of 50 states in United States from World Resource Institute from 1990 to 2018. I also gather data of total acreage of certifies organic pasture and cropland combined for each state in 50 states in United States from United States Department of Agriculture (USDA) from 2000 to 2011. Due to missing values from the datasets from USDA, only panel data from 2000 to 2008 are included in my research. After combining the two datasets, the total number of observations is 450, although there are remaining missing observations for total organic acres across 50 states, especially in 2000 and 2001. Missing values are assumed equal to 0 to consistent with other datasets. Table one represents variable description that I use in my model.

Table 1. Variable Description Table

Variable	Description	Unit of Measurement
state	State in United States	

totalC02	Total greenhouse gas emissions including emissions from land use, land-use change, and forestry (LUCF)	Million metric tons of carbon dioxide
total_organic_arces	The total acreage of certified organic pasture and cropland combined for each state in the corresponding year.	Acreages
total_organic_thousands_of_arces	The total of thousand acreages of certified organic pasture and cropland combined for each state in the corresponding year	Thousands of Acreages
state_gdp	Gross Domestic Product (GDP) of the state in millions of US dollars	Millions of US dollars
population	Population of the state	Number of people

Table 2 provides a descriptive summary of the statistics for the variables used in my analysis. The two variables also seem to be correlated since a significant portion of CO2 emission come from production and consumption of energy such as coal, oil, and natural gas. Therefore, it makes sense that, in regions or states where energy consumption is high, CO2 emission are also likely to be high especially if the energy is produced from carbon-intensive sources. For example, Vermont had the lowest energy consumption at 6.09 million metric tons of CO2 equivalent (MtCO2e) in 2008, which correlated with the lowest total GHG emissions in the same year. Conversely, Texas recorded the highest level of total GHG emissions and energy consumption in 2002. The variables show substantial variability, as indicated by the relatively

high standard deviations, especially for the variable of primary interest—total_organic_acres. Recall, zero was used to represent missing values, with a total of 11 missing observations for the total_organic_acres variable. Even disregarding the missing data, the minimum observed value for total organic acres is quite low; for instance, Connecticut reported only one acre of organic farmland in 2002.

Table 2. Summary Statistics

Variable	Obs.	Mean	Median	Std. Dev	Min	Max
totalCO2	450	121.06	86.11	118.7	5.98	726.561
state_gdp	450	242164.1	146550.5	288756.6	19952	1763450
population	450	5848318	4166520	6420459	494300	3.66e+07
total_organic_arces	450	60276.1	18767.24	122034.7	0	1460205
total_organic_thousands_of_acres	450	60.28	18.78	122.03	0	1460.2

To explore the connection between organic farming and greenhouse gas (GHG) emissions, I construct the following econometric model:

$$totalCO2_{it} = B_o + B_1 total\_organic\_thousands\_of\_acres_{it} + B_2 state\_gdp_{it} +$$
$$B_3 population_{it} + t_t + a_i + v_{it}$$

Here, i indexes each state and t indexes each year. The variable t_t captures the time-fixed effect while a_i captures the state fixed effect. The dependent variable of my model is totalCO2, measures the total carbon emissions, and our primary explanatory variable of interests is total_organic_acres, the acreage devoted to organic farming, is re-scaled to total_organic_thousands_of_arces to make it easier to keep track and interpret. I also include states GDP and population as explanatory variables, due to their established correlation with total GHG emissions (McGee, 2014). Based on the paper hypothesis, I expect that the coefficient on total organic acres to be negative, suggesting that an expansion in one organic farming acreage correlates with a MtCO2e decrease in total GHG emissions.

Results

Table 3 displays regression results across three distinct model specifications: pooled Ordinary Least Squares (OLS) and two fixed effects models for panel data, incorporating state GDP and population as control variables. The initial fixed effects model incorporates only state-fixed effects, while the third model additionally includes year-fixed effects. Given the use of

pooled OLS in multi-year panel data can produce endogeneity, leading to biased estimates, the analysis primarily focuses on the fixed effects models.

According to pooled OLS model, the result shows a significant correlation between the total thousands of acreages of certified organic and total greenhouse gas emission. This indicated an increase of one thousand acres in the total thousands of acreages of certified organic is associated with a 0.088 million metric tons of carbon dioxide in total greenhouse gas emission. This result goes the opposite side of my prediction as increase in organic farming led to increase in greenhouse gas emission. The state GDP is positively linked with emissions, where a one million USD increase correlates with a 0.0007 million metric ton rise in carbon dioxide emissions. Similarly, population growth shows a significant positive correlation, with each million USD increase associated with a 4.80e-05 million metric ton increase in emissions.

The first fixed effects model, which controls for state-fixed effects, shows that the earlier positive association between organic farming acreage and emissions becomes statistically insignificant, indicating that controlling for unobserved state-level effects renders the initial observed impact undetectable. Both state GDP and population also turn insignificant in this model. The R-squared of 0.021 suggests that a minimal variation in emissions is explained by this model when accounting for state-level effects.

With the inclusion of year-fixed effects, the coefficient for organic acreage shifts towards the expected negative direction, though it remains insignificant, implying that organic acreage does not statistically predict emissions levels when holding other factors constant. The slight increase in R-squared to 0.132 still indicates a minimal explanatory power of the model concerning variations in greenhouse gas emissions.

Table 3. Result Table

VARIABLES	Total Greenhouse Gas Emission		
	OLS	FE-1	FE-2
The total of thousands of acreages of certified organic	0.0882**	0.000587	-1.51e-05
	(0.0401)	(0.00331)	(0.00274)
State GDP	0.000746***	5.55e-05	2.67e-05
	(0.000103)	(7.17e-05)	(7.39e-05)

Population	4.80e-05***	-4.94e-06	-4.26e-06
	(5.08e-06)	(9.54e-06)	(9.94e-06)
Year 2001			-2.269**
			(0.872)
Year 2002			-1.248
			(1.118)
Year 2003			-0.174
			(1.256)
Year 2004			2.275
			(1.435)
Year 2005			2.611*
			(1.323)
Year 2006			1.098
			(1.649)
Year 2007			2.947
			(1.928)
Year 2008			-0.827
			(2.211)
Constant	15.52**	136.5***	139.0***
	(6.108)	(41.71)	(44.19)
Observations	450	450	450
R-squared	0.734	0.021	0.132
Number of stateID		50	50

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Discussion and Conclusion

The result shows that the total of thousand acreages of certified organic pasture and cropland does not statistically predict the total of greenhouse gas emission in United States as I hypothesized. This finding is consistent with Bos et al (2015) which shows that organic farming does not reduce greenhouse gas emissions but would rather contribute the opposite. Bos et al

(2015) highlight several reasons why organic farming does not necessarily result in reduced greenhouse gas emissions. Firstly, organic farming practices are characterized by their high intensity, involving crop rotations that include a significant proportion of high-value crops. This intensive cultivation requires relatively high inputs of fertilizers and frequent field operations, especially for weed control, which increase energy consumption. Furthermore, organic methods often yield lower per-hectare productivity compared to conventional approaches. This reduced efficiency means that producing the same quantity of food requires more land and more resources, potentially offsetting the environmental benefits typically associated with reduced synthetic pesticide and fertilizer use in organic systems. Consequently, these factors contribute to the higher energy usage and associated greenhouse gas emissions in organic crop production compared to conventional methods, undermining the potential climate benefits of organic agriculture under these conditions (Bos et al., 2015).

The two fixed effects models display relatively low R-squared values, indicating that they do not extensively explain the variability in total greenhouse gas emissions. However, given that our primary objective is to control for endogeneity to ensure accurate estimations, the fixed effects model remains a suitable option.

The study has some limitations in term of data and methodology. There are significant gaps in the dataset, particularly with the data on the total acreage of certified organic pasture and cropland from the USDA, which only covers the years 2000 to 2008. The analysis assumes missing values as zero, which could introduce bias or inaccuracies in the results, especially if the actual values significantly deviate from zero. Also, the econometric model relies on assumptions that may not hold across different contexts or scales. In this case, the relationship between organic farming acreage and greenhouse gas emissions is assumed to be linear and direct, which might not account for complex interactions or delayed effects. Real-world phenomena often involve complex interactions that can be nonlinear or influenced by multiple factors. For instance, the effect of increasing organic farming on greenhouse gas emissions might vary significantly depending on soil types, local climate conditions, and the types of crops grown (Carbonell-Bojollo et al., 2019). These are not necessarily linear and may have. Also, the impact of changes in farming practices on greenhouse gas emissions might not be immediate. There can be delayed effects as ecological systems adjust to new practices. For example, the soil might take several years to fully respond to organic farming practices in terms of its carbon sequestration

capabilities (The NCO Team, 2023). Suggestion for further research would include improving data handling techniques by employing more sophisticated methods for dealing with missing data and incorporating non-linear models techniques that can handle complex interactions between variables might provide more nuanced insights into the relationships between organic farming and greenhouse gas emissions.

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