Energy Efficiency and CO_2 Emissions in the Greenhouse Industry: Evidence from Michigan

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Abstract

Greenhouse production is one of the most energy intensive branches of agriculture. High energy costs and increasing environmental concerns associated with the greenhouse gas emissions are posing an increasing threat to the industry. To address the emerging challenges, greenhouse growers will have to improve energy efficiency and reduce CO2 emissions. Based on a recent industry survey, this research provides comprehensive information on Michigan greenhouse industry. We measure CO_2 emissions and analyze energy efficiency of the industry. Results show that the average CO2 emissions are well beyond the threshold stipulated in the Clean Air Act and that energy efficiency can be significantly improved.

Keywords: CO2 emission, energy efficiency, greenhouse gas emissions, greenhouse industry, Michigan

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Introduction

Michigan's greenhouse floriculture industries continued to grow in 2008 with sales of $393.5 million for floriculture products, ranking third in floriculture production output behind California and Florida (NASS, 2009a). According to the Michigan Department of Agriculture, floriculture and nursery crops accounted for 11% of agricultural cash receipts in the state in 2007 and was the third largest segment of agriculture, behind milk and corn production (Runkle, 2010).

However, greenhouse production is one of the most energy intensive branches of agriculture. The high and volatile energy prices observed in 2008 have caused tremendous concerns among greenhouse growers. As a traditionally important user of energy, greenhouse production also leads to large amount of CO2 emission due to the use of fossil fuels in heating. The environmental concerns arising from greenhouse gas emissions and their global warming effects have been one of the most important issues of the society. Several recent development regarding energy use and CO2 emissions have come into focus. The most important change is that Obama government is adopting an engaging policy in a global greenhouse gas emission negotiation and is ready to commit to a policy that aims to reduce emissions by 17% over the 2005 level by 2020 and further reduce them by an additional 80 percent by 2050 (Stern, 2009). The cap-and-trade regulation has been under heated debate. The public environmental concerns and possible regulations on greenhouse gas emissions have been pressuring the industry and created increased uncertainties to greenhouse businesses.

To adjust to the high and volatile energy prices and imminent regulations on greenhouse gas emissions, greenhouse growers need to adapt to high energy cost and seek to improve energy conservation and/or shift to alternative energy sources in the greenhouse production. The primary objectives of this study are: (1) to provide the latest information of greenhouse production in Michigan based on an industry survey and to review important issues related to energy use in the production process, (2) to measure CO2 emissions in the greenhouse industry, (3) measure production and energy use

[1] The authors would like to thank Stephen Harsh, Erik Runkle, Robert Myers, Jeanne Himmelein, and Tom Dudek for all their help and discussions. Without them this study would not have been possible. All errors are the authors'.

efficiency and investigate the potential for energy conservation and CO2 emission reduction. The purpose of our study is to provide information and insights to help the industry make production and investment decision and adjust to the changing policy environment, and to facilitate government environmental policy making.

Industry Survey

Quality production information at the firm level in the greenhouse industry is generally lacking for robust economic analysis. To achieve the objectives of this study we conducted an industry survey and collected primary data from greenhouse growers. Our survey focused on the whole production process and covered both economic and technical aspects. Greenhouse growers were requested to provide both general information on their operation and information on technology and energy use. General information requested includes information on operator demographics, firm background, firm revenue, investment, labor, and materials used in the production. The survey further collected information on greenhouse covering, heating technology, energy sources and cost. Questionnaires were sent to 728 growers in Michigan in January and February 2009 in a mailed survey using the mail list of the National Agricultural Statistics Service (NASS). Responses were returned during a 4-month time frame from February to May 2009. A total of 360 questionnaires were returned. Of the returned questionnaires, 328 were completed and are used for this study. The response rate was 49%, reflecting the interest of respondents and the relevance and timeliness of this study.

In this paper we first summarize the survey results and then conduct an in-depth analysis on the economic and environmental performance of the industry, with an emphasis on production and energy efficiency.

Overview of Michigan Greenhouse Industry

General Information

The high and volatile energy prices observed in 2008 raised tremendous concerns among growers. Growers were first asked about their perception about future energy price movement. Most respondents predict that energy prices will increase in the near future. But they have different perceptions about the rate of increase in the next 2 year. Overall 54.9% believe prices will increase at historical rates, 50% believe prices will increase faster than historical rates, 49.1% believe prices will stay the same[2]. However, there are still 18% think the prices will decrease in the next 2 year. When asked about energy prices in the next 5 years, 58% think prices will be increasing at historical rates; 51% choose faster than historical rates, 37% believe prices will stay about the same and 13% think that prices will decrease. Note that the survey was conducted in the time of deep recession. Looking beyond the recession in a 2- and 5-year frame, most growers believed that the price will be increasing at the historical rates or faster.

Respondents are also asked whether they are downsizing or expanding their greenhouse operation in the next 3 years. 46% choose neither to expand nor to downsize; 28% choose downsizing and 26% choose expansion. Major factors for downsizing include:

- Uncertain economic condition and poor business environment.
- Shrinking greenhouse products market and declining sales.
- High operation (energy) costs
- High overhead costs
- Competition
- Age problem (retirement)
- Debt problem

The major reasons that support expansion are:

- Increased demand for greenhouse products.
- Increased sales and profits.
- More space needed for certain products (e.g. organic vegetables).
- Economy of scale / efficiency

There are fewer reasons for expansion and they are mainly due to perceived market conditions and economy of scale.

The following two figures illustrate the years that the greenhouse operation was established and last added on, and the geographic distributions of Michigan greenhouse firms. It shows that about a quarter of the greenhouse firms were established in 1980's and about two thirds have added on in the past decade. Approximately 60% growers have used their facilities for less than 15 years. Southeast Michigan has 32% of the greenhouse firms, the most concentrated area in Michigan, which is followed by Southwest 27%.

Figure 1. Year established and last added on, Michigan, 2008

[2] Respondents were allowed to check multiple choices, so the percentage does not add up to 100.

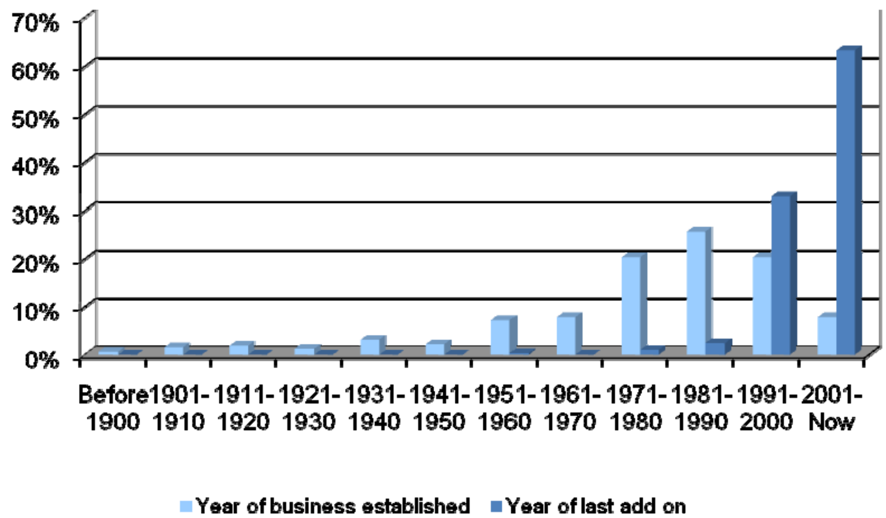
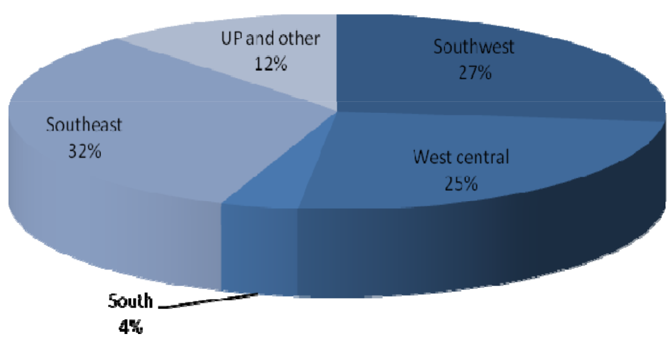


Figure 2. Geographic distributions of greenhouse operation, Michigan, 2008



The primary decision makers of most greenhouse firm owners and operators are predominantly male (84%). Table 1 presents information on growers' education. 33% have a 4-year college degree or advanced degree. However, only 27% of this group studied horticulture or agriculture. 35% of respondents have a high school degree, and 26% have post high school training or some college. Only 5% of respondents have a less than 12-year education.

The largest age group of primary decision makers is the 45-54 group (37%). 31% in the 55-64 age group and 17% in the 65 and over age group. Respondents younger than 45 years account for 15% of the sample. Overall 22% greenhouse firms do not have influential person assisting decision making. Among those 78% that do have influential persons assisting, the education distribution is roughly the same as those for the primary decision makers. 17% of the influential persons assisting had a college study in horticulture or agriculture. The largest age group of most influential person assisting decision making was also the 45-54 group (33%).

Table 1. Education level of owners and operators, Michigan, 2008

Education level	Primary decision maker	Most influential person assisting
Less than grade 12	5.07%	5.19%
High school graduate	35.47%	37.26%
Post high school training/ some college	26.35%	24.06%
4-year college degree	21.28%	22.17%
Advanced college degree	11.82%	11.32%

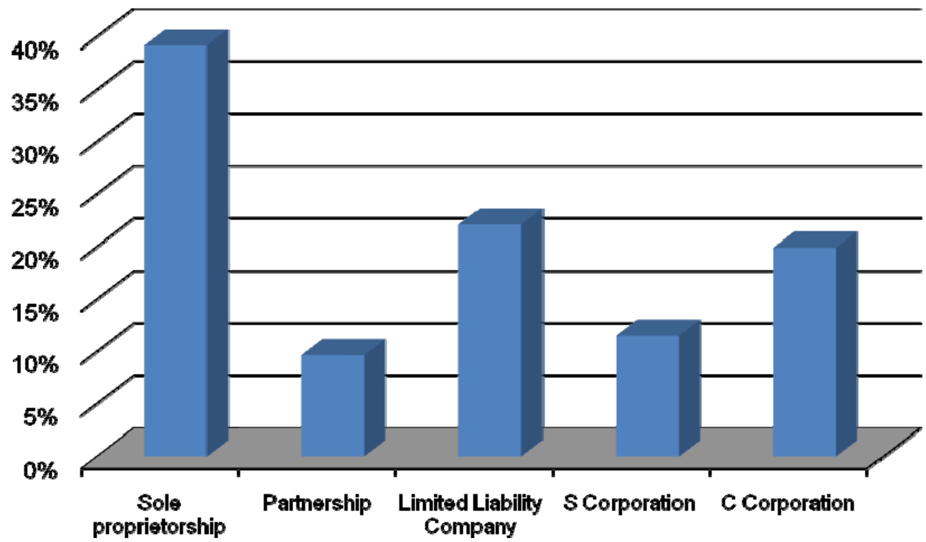
Survey participants were also asked what service their greenhouse operation used in the last 3 years (Table 2). Among the five given choices, accounting is most widely used service, with 66% growers using it. Michigan State University extension service was used by 55% of participants, indicating significant demand in MSU extension service.

Table 2. Service type used by greenhouse operators, Michigan, 2006-2008

Service	MSU extension	Lawyer	Accounting service	Paid consulting	Consulting from agri suppliers
Percentage	55.25%	28.40%	66.05%	11.11%	26.23%

As for the ownership, the majority firms are family owned and operated. Sole proprietorship is the most popular organization, accounting for 38%. C Corporations account for 19% of the sample. Partnership, LLC and S Corporation account for 9%, 22%, and 11%, respectively (Figure 3). Our survey further shows that 35% greenhouse operations have two partners, which is interpreted as husband-wife business partners.

Figure 3. Ownership structure of greenhouse operation, Michigan, 2008



How important is this business to greenhouse owners and operators? Of all respondents, 60% think the income is "very important", 26% think it is "important", 8% hold a "neutral" opinion, and 6% think this income is "not so important" or "not at all". 40.5% growers reported they do not earn money other than greenhouse operation, which means this is the only source of income.

Investment

An important option for producers to increase energy use efficiency is to invest in energy-saving technologies. In this section of the survey, greenhouse operators were asked to provide capital investment and other financial information.

In the last 3 years, 96%, 35% and 23% growers spent money on maintenance, replacement and addition of new construction, respectively. The average expense on maintenance, replacement and addition of new construction are $43,855, $43,527 and $38,705, respectively.

Table 3 presents information related to capital assets of greenhouse operations. The average book value of depreciable greenhouse operation assets is $0.63 million and the estimated current market value is $0.60 which does not show significant deviations. Further examination of data shows that the medians of the book value and market value are $0.2 million and $0.15 million, respectively, suggesting highly skewed distributions and the existence of some very large operations. The mean land value is $0.22 million; the value becomes $0.31 if used for commercial development.

Growers were further asked about their investment plans. Investment planned for energy saving and heating systems accounts for about 15% to 18%. Table 4 presents a summary of some additional financial information.

Table 3. Investments of greenhouse firms, Michigan, 2008

	Mean	Median	St. Dev.
The book value of total investment	630,770	200,000	1,586,742
Estimated current total market value	601,531	150,000	1,485,740
Land valued for greenhouse purposes	222,540	90,000	495,909
Land if used for commercial development	307,816	10,000	643,425
Maintenance	43,855	10,000	123,218
Replacement	43,527	0	224,468
Addition	38,705	0	191,999
Investment in next 2 years	58,054	0	250,094
Percentage for energy saving and heating	18	0	32
Investment in next 3-5 years	119,879	0	655,376
Percentage for energy saving and heating	15	0	29

Table 4. Some Financial Data, Michigan, 2008

	Mean	Median	St. Dev.
Book value of all assets	1,046,800	435,000	1,118,589
Market value of all assets	952,241	350,000	1,733,885
Debt	305,741	50,000	953,768
Gross profit	601,710	80,000	1,987,669
Total sales	1,055,795	180,000	3,600,122
Total costs	549,762	64,800	2,499,466

Labor

Greenhouse operation is labor intensive. Most greenhouses have peak labor requirements from February to June in Michigan. Participants were requested to provide labor use information, both paid and unpaid labor. The total expenses of paid labor, including benefits, are approximately $272,670 per firm on average, ranging from $0 to $6.4 million, with median $40,000. About 55% firms spend less than $10,000 on hired worker in the whole year. Greenhouse operators also estimated the value of unpaid labor, including unpaid labor from managers, operators, and other family members. The average is $22,684, ranging from 0 to $320,000, with median $2,500. Detailed labor use information is reported in Table 6.

Table 6. Family and hired labor use, Michigan, 2008

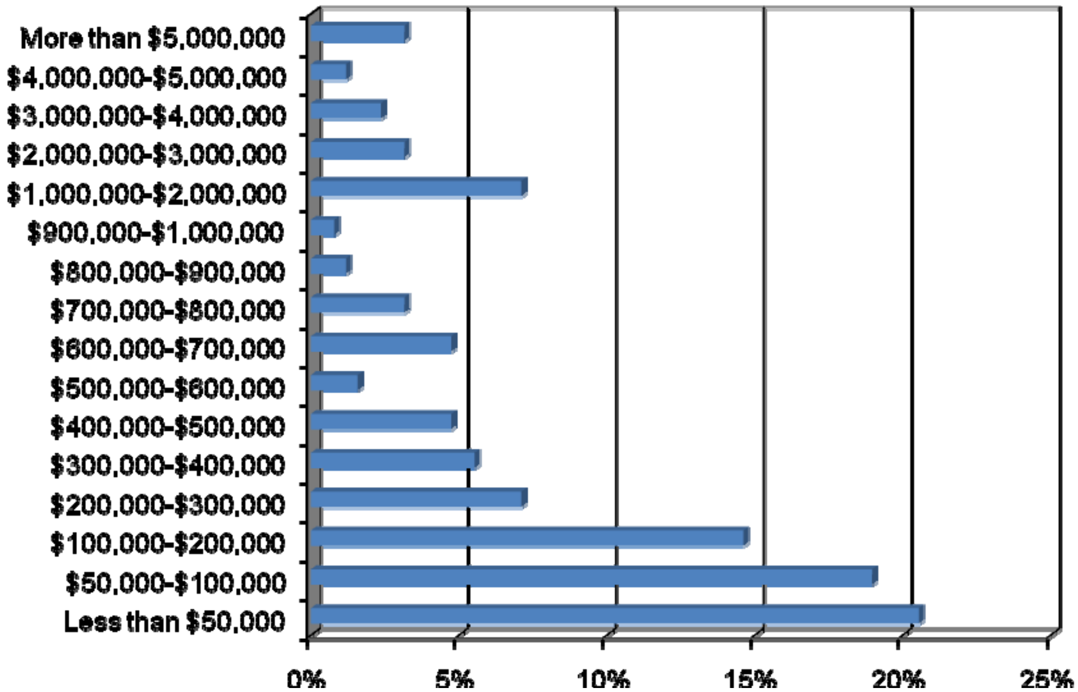
		Mean	Median	St. Dev.
Unpaid labor: manager/ operator	Numbers of workers	1.22	0	3.05
	Average months worked per worker	4.62	3.5	6.01
	Average hours worked per month	97.38	20	125.70
Unpaid labor: other family members	Numbers of workers	0.72	0	3.71
	Average months worked per worker	1.51	0	3.28
	Average hours worked per month	31.64	0	80.03
Paid labor: year round, incl. manager/family	Numbers of workers	93.80	1	1488.50
	Average months worked per worker	5.55	2.5	6.21
	Average hours worked per month	75.41	0	88.69
Paid labor: seasonal/temporary	Numbers of workers	124	4	1852
	Average months worked per worker	3.14	3	2.65
	Average hours worked per month	89.24	80	98.62

Survey results indicate that labor expenses comprised 39% of the variable operating costs. On average, paid and unpaid labor account for approximately two thirds and one third of the total labor costs, respectively. The average wage rate of paid labor, including benefits, was $17.2 per hour in 2008. The average rate for unpaid labor was estimated to be $25.20 per hour. But note that the rate for unpaid labor was subjective.

Greenhouse revenue and operating costs

Survey results show 60% of respondents had sales $100,000 or higher in 2008. The mean and median of sales were $1,055,795, $180,000, respectively. Because of the existence of some large firms, the median value better reflects the average level of total sales.

Figure 4. Total sales of greenhouse products, Michigan, 2008

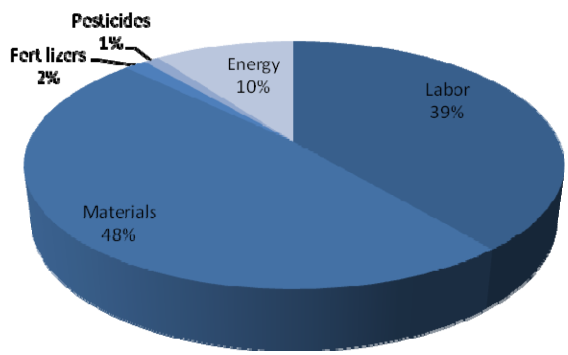


Major operating costs of greenhouse business include labor, material, energy, and overhead, etc. Based on our survey, the two largest proportions of operating costs were materials (48%) and labor (39%). Energy cost hit historical record in 2008, but our survey shows that total energy cost only accounts for 10% of the operating costs. This may be because the energy market peaked in July/August in low energy consumption season for greenhouse firms, while the second half of 2008 saw dramatic drop of energy prices due to the recession, which should have significantly reduced energy cost.

Table 8. Estimated cost of greenhouse operation, Michigan, 2008

	Mean	Median	St. Dev.
Supplies	342,474	31,000	1,661,539
Fertilizer	10,863	1,500	44,593
Pesticides	7,731	1,000	27,299
Utilities	74,953	12,000	218,488
Other	101,715	0	700,237

Figure 5. Average variable cost share across firms, Michigan, 2008



Greenhouse covering and heating technology

Growers can reduce energy use and address high energy cost by adopting alternative covering or heating systems, energy sources, or production practices. Greenhouse covering and the heating system are two of the most important determinants in efficient heating of a greenhouse.

The selection of cover materials and heating technology has a tremendous influence on the greenhouse production. Four types of greenhouse covering and the area under these covers are presented in Table 8. Poly film is the most common greenhouse covering film in the United States (Giacomelli and Roberts, 1993). This simple, less costly covering has also been widely used in Michigan. 88.7% greenhouse firms used double layer poly as one type of covering. Double-layer poly film covers largest production area, followed by glass greenhouses. The average area under double poly and glass greenhouse are approximately 72,000 and 52,000 square feet, respectively.

Table 8. Greenhouse production areas in square feet, Michigan, 2008

	Mean	Median	St. Dev.
Glass greenhouse	51,951	19,500	80,222
Rigid plastic greenhouse	23,897	10,000	54,869
Double layer poly	72,376	19,200	161,897
Single layer poly	32,194	5,000	91,389

Survey participants also provided detailed information about area heated by each type of heating technology under different coverings. Vented unit heaters are the most widely used heaters, with 77.9% operators using this type of heater under double-layer poly in Michigan. Of all valid responses, 70% operators used only one type of heater, of which 91.9% used vented unit heaters. 17.9% operators used two type of heaters, and most of them used the combination of vented unit heaters and one of the other types.

Table 9. Percentage of greenhouses heated by each type of heaters[c], Michigan, 2008

Heater type	Glass greenhouse	Rigid plastic	Double layer poly	Single layer poly
Vented unit heaters	11.22%	13.78%	77.88%	*
Non-vented unit heaters	1.28%	1.28%	4.17%	*
Non condensing boiler	4.81%	2.88%	7.05%	*
Condensing boiler	4.81%	2.24%	5.45%	*
Biomass boiler	0.64%	0%	3.53%	*
Geothermal	0%	0%	0%	*
Other	0.32%	0%	6.14%	*
Not heated	0.64%	0.64%	4.81%	14.10%

[c] Firms may use multiple types of heating technology, so the percentages of each covering category do not add up to 100%.

Energy Use

Natural gas is the primary source of fuel for the commercial greenhouse growers. In rural areas where natural gas facilities are not available propane are often used. Electricity is usually used as supplementary energy. In our sample, 67.4% growers use natural gas as one of the energy sources for greenhouse heating in 2008, ranking 1st among all the fuel types. The next most widely used fuel types are propane and electricity, with 36.9% and 22.9% growers using them, respectively. Specifically, 68.8% growers used only one type of energy for heating, of which, 58.8% used natural gas and 35.7% used propane. 26.8% growers used two types of energy for heating, of which, 64.3% used the combination of natural gas and electricity; 15.5% used the combination of natural gas and propane.

Table 10 reports the costs of energy use. As the most used fuel type, the cost of natural gas ranks 1st among all energy costs.

Table 10. Greenhouse energy cost, Michigan, 2008

Technology	Mean	Median	St. Dev.
Natural gas	88,233	22,724	206,167
Electricity/geothermal	33,872	5,500	81,818
Heating oil(No.2)	5125	4,750	3,247
Propane	18,176	7,000	32,877
Coal	2,100	2,100	*
Corn	1,850	1,850	919
Other bio-mass	1,817	1,200	1,760
Other	5,589	1,123	12,356

Analysis shows that \$1 energy input is required to produce every \$18.20 sales and \$5.8 gross profit. But these ratios vary across different firms and different fuel type. Among firms that used only one source of energy, approximately \$1 natural gas is required for every \$16.59 sales and \$7.64 gross profit, whereas \$1 propane is required for every \$17.26 sales and \$5.90 gross profit.

Table 11. Energy productivity and average CO2 emissions

	Mean[3]			Median		
	Overall	Natural Gas	Propane	Overall	Natural Gas	Propane
Sales/Energy cost	18.20	13.94	11.24	11.43	12.50	4.76
Gross Profits/Energy cost	5.80	5.66	5.34	4.50	4.34	9.25
CO2/Sales	1.10	1.10	0.62	0.84	0.83	0.53

[3] Means are calculated after removing 5, 3, and 3 highest and lowest values considered to be outliers for overall natural gas, and propane, respectively.

CO2/Gross Profits	2.28	3.48	0.79	1.75	0.53	0.83

When analyzing fuel type performance, the heat value and market prices of different fuels have to be considered. Heat value differs among fuel types. It differs even for the same fuel type when used in different heating systems with different conversion efficiency. By incorporating fuel prices (Table 12), it is possible to compare the costs of using different heating fuels. As an example, assume both propane heating oil and natural gas are used in conventional boilers (the heaters have the same efficiency). Table 12 shows a thousand cubic feet of natural gas will generate 1,030,000 Btu of heat. 7.43 gallons of No. 2 heating oil can be converted into approximately the same amount of heat. In 2008, Michigan natural gas industrial price was $10.21 per thousand cubic feet on average, and the No.2 heating oil industrial price was $3.29. It is clear that the heating oil price would have to decrease to $1.37 per gallon before heating with oil becomes as cost effective as natural gas. Rapidly increasing crude oil prices have made heating oil even more inefficient. Note that propane, a relatively widely used fuel in Michigan, has similar level of cost efficiency as heating oil in terms per unit heat. Overall, natural gas is among the most cost effective fuel, together with coal and wood.

Table 12. Heating fuel comparison calculator

Fuel type	Fuel unit	Fuel price per unit[d] (Dollars)	Fuel heat content per unit (Btu)	Fuel price per Million Btu (Dollars)	Heating Appliance Type	Efficiency (%)
Natural Gas	1000ft[3]	$10.21[4]	1,030,000	$9.91	Furnace or Boiler	78%
					Vented heater	65%
					Non-vented heater	100%
Electricity	KWh	$0.07[5]	3,412	$20.55	Furnace or Boiler	98%
					Air-Source Heat Pump	226%
					Geothermal Heat Pump	330%
Fuel Oil	Gallon	$3.29[6]	138,690	$23.72	Furnace or Boiler	78%

4 http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_a_EPG0_PIN_DMcf_a.htm
5 http://www.eia.doe.gov/cneaf/electricity/epm/table5_3.html
6 http://tonto.eia.doe.gov/dnav/pet/pet_pri_wfr_a_EPD2F_PRS_cpgal_w.htm

(#2)						
Propane	Gallon	$2.19[7]	91,333	$24.01	Furnace or Boiler	78%
					Vented heater	65%
Coal	Ton	$200.00[8]	26,000,000	$7.69	Furnace/Boiler/Stove	70%
Corn (kernels)	Ton	$200.00[9]	16,500,000	$12.12	Vented heater	68%
Wood	Cord	$200.00[10]	22,000,000	$9.09	Vented heater	55%

Data source: partly from www.eia.doe.gov/neic/experts/heatcalc.xls

[d]Energy prices from http://www.eia.doe.gov/

CO2 Emissions

Greenhouse firms produce not only flowers and plants but also emit CO2, an "undesirable output" that contributes to global warming. Currently greenhouse growers are not subject to emission restriction. However, given the recent policy developments at the state, national, and international level, this may change in the future.

In this study we measure the direct CO2 emissions that take place within the firm, generated by burning fossil fuels which are the primary source of CO2 emissions for greenhouse firms. Table 13 presents the CO2 emission coefficients for each fuel type, which refers to the quantities of CO2 emissions per unit.

Table 13. CO2 emission coefficients[e]

Natural gas (lb/1000ft3)	Electricity (lb/kWh)	Heating oil (No.2) (lb/gallon)	Propane (lb/gallon)	Coal (lb/ton)
120.59	1.50	22.38	12.67	5685

[e] Data source: http://www.eia.doe.gov/oiaf/1605/coefficients.html

An average Michigan greenhouse firm generated 837,917 (median 115,645) pounds of CO2 due to energy use. Converted to metric tons, the average emission is 380 tons, well beyond the emission threshold of 250 tons stipulated in the Clean Air Act. Further analysis shows that each dollar of sales and profit generated approximately 1.10 and 2.28

7 http://tonto.eia.doe.gov/dnav/pet/pet_pri_wfr_a_EPLLPA_PRS_cpgal_w.htm
8 http://www.eia.doe.gov/cneaf/coal/page/acr/table28.html
9 http://www.ers.usda.gov/data/priceforecast/
10 http://www.globalwood.org/market/market_prices_america.htm

pounds of CO_2, respectively. CO_2 emissions vary with firm sizes. Large firms with sales over $100,000 generated 0.96 pounds of CO_2 per dollar of sales and 2.35 pounds per dollar of profit,, whereas small firms with sales less than $100,000 generated 1.32 pounds of CO_2 per dollar of sales and 1.80 pounds of CO_2 per dollar of profit.

Alternative Energy Sources

The high fossil fuel prices have significantly increased growers' interest in less expensive energy sources while environmental issues associated with the use of fossil fuels are driving greenhouse growers to look for cleaner fuel options, such as biomass fuels because this type of energy contains "biogenic" carbon, which is part of the natural carbon balance and will not add to atmospheric concentrations of CO_2.[11] More and more growers are expected to be shifting to the use of alternative fuel sources. There are a variety of alternate fuels available to heat a greenhouse, including biomass fuels for incineration (woodchips, sawdust, pelletized agricultural- and wood-based products, etc.), biofuel, and biogas.[12] We found some evidence that alternative fuels are being used in Michigan. According to our survey, 13.6% growers used biomass fuels as their supplementary energy, and roughly 3% growers used it as the only one source of energy.

Production and energy efficiency

Method

Greenhouse production is a multiple inputs-multiple outputs process. The preceding sections analyze the industry performance using financial ratios and energy output-input ratios, which are easy to compute and understand. However, output (sales) per dollar of certain input (energy) discussed, for example, does not take into account all other inputs used and therefore presents an incomplete picture. This section focuses on growers' production efficiency, energy use and CO_2 emission efficiency, accounting for all outputs and all inputs in the production process. We focus on two efficiency measures: overall production efficiency and energy use efficiency.

[11] Intergovernmental Panel on Climate Change. *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3, Pg. 6.28, (Paris France 1997).

[12] http://www.thebioenergysite.com/articles/245/use-of-biomass-for-heating-greenhouses

We employ the Data Envelopment Analysis (DEA) approach to measure efficiency of greenhouse firms. This approach has been widely used in the literature to measure and compare firm performances (Coelli et al., 2005). The following graph illustrates the concept of overall production and energy use efficiencies.

Figure 6. Illustration of production efficiency and energy use efficiency.

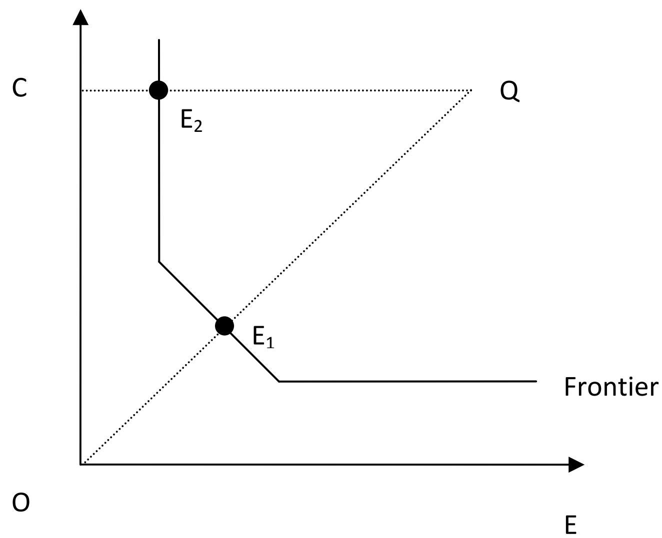


Figure 6 illustrates the basic idea behind the methodology in a simplified two-input case. In the figure, firms are producing one unit of output (sales) with different amounts of energy and capital. Firms on the frontier at points E_1 and E_2 are most efficient because they use minimum amount of inputs and it is not possible for them to lower the use of one input without increasing the use of the other. The frontier curve represents the best performing firms. Firms outside the frontier, at point Q for example, are inefficient because they use more inputs. The farther firm Q is away from the frontier, the less efficient it is. Firm production efficiency can be measured as the ratio of OE_1/ OQ, which assumes that the two inputs continue to be used in the same proportion as the frontier is approached. Energy efficiency can be measured as the ratio of CE_2/CQ, which assumes the frontier is approached by reducing the energy input only while holding capital use fixed (see, e.g. Guan and Lansink, 2003). Efficiency scores lie between 0 and 1, with values equal to 1 indicating that the firm is fully efficient, i.e. it is located on the production frontier.

Data and Results

We computed the overall production efficiency and energy use efficiency scores for each firm using the DEA method. The table below presents one output and five inputs variables used in the model.[13] The output is measured in sales. Five inputs used are capital, land, labor, materials, and energy. Land is the production area under greenhouse; materials consist of supplies, fertilizers, and pesticides.

Table 14. Summary statistics of output and inputs used in efficiency measurement.

	Unit	Mean	St. dev.	Median
Output				
sales	Dollars	1.53E+06	5.07E+06	170,000
Inputs				
Capital	Dollars	856,266	2.07E+06	250,000
Land	Square feet	108436	220,712	21,500
Labor	Man hours	21,303	50,383	7,380
Materials	Dollars	508,895	2.19E+06	40,000
Energy	BTU	97,473	275,510	16,250

The DEA results show that the average production efficiency scores is 0.64, indicating substantial inefficiencies in Michigan greenhouse operations of sample firms. The firms could, on average, reduce the use of all inputs by 36%, while being able to produce the same amount of output. The efficiency level found in our study is low compared to the results found in similar studies conducted for the Dutch greenhouse firms (Lansink and Bezlepkin, 2003). Among the sample in our study, the efficiency score ranges from 0.1585 to 1 with median 0.60. The scores vary tremendously cross firms; 56% of firms used in the calculation have the scores under the average value. About 26% of firms were identified as fully efficient (score equal to 1).

The energy use efficiency scores demonstrated even larger inefficiencies. The average efficiency was only 0.54, with median 0.42. These firms could reduce the use of energy by 46% keeping other inputs unchanged, to produce the same amount of output. It is clear that overall firms were highly inefficient in the use of energy, and that substantial decrease in energy use can be achieved if the best performing firms' technology and practice are used. Greenhouse firms are, on average, far from the production frontier.

[13] Missing values and outliers are removed to ensure robust analysis.

Generally, low energy use efficiency leads to low level of CO_2 efficiency because of high positive correlation between these two efficiency indicators. Note that the measure of CO_2 emissions in this study only accounts for the emissions taking place in the heating process due to direct energy use. Low CO_2 efficiency also shows that there is considerable potential for decreasing CO_2 emissions using the currently available technologies as represented by the production frontier.

Conclusions

The growing importance of the greenhouse industry to Michigan agriculture and its intensive energy use have made the industry a unique object for research in the current economic and policy environment. To identify the factors that affect the performance of greenhouse operations and provide information to producers and service providers, our research has highlighted important issues in the industry which are of interest for different stakeholders of the industry, including individual growers, the industry, policy makers, and educators.

In this study, we first summarized the general information regarding firms and operators characteristics and operators' perceptions of future energy prices, and then conducted an efficiency analysis to assess the potential for energy efficiency improvement and reductions of CO_2 emissions.

When asked about market prospects, only 18% (13%) of participants believe that energy price will decrease in the next 2 (5) years. The majority believe that the price will increase at or faster than the historical rate. 28% firms plan to downsize their business while 26% firms consider expanding. 46% of the growers and operators choose to stay the same.

Sole proprietorship is most popular organizational form, accounting for roughly 40% of the sample. C Corporation also makes up a significant share (approximately 20%). The average value of greenhouse firms is 1 million, of which capital assets amount to 0.63 million. The survey results show that only 15% of firms are operated by owners younger than 45 years of age, suggesting an ageing industry. One third of the operators have college or advanced degrees.

The cost pie shows that materials, labor, and energy are the largest three cost items in greenhouse operations, which account for 48%, 39%, and 10% of the operating costs, respectively. We found that double poly film is the most widely used greenhouse covering in Michigan, with 89% of growers using it as one types of coverings. The heating systems are dominated by vented unit heaters, with 78% of operators using it under double poly layer. Greenhouse firms have used natural gas as their primary source of fuel to heat their greenhouses, ranking 1st among all fuel types.

Our analysis shows that $1 of energy input is required for every $18.2 and $5.8 of sales and gross profit, respectively; each dollar of sales and profit generated approximately 1.10 and 2.28 pounds of CO_2, respectively. The average CO_2 emission is 380 metric tons per firm, well beyond the threshold stipulated in the Clear Air Act. In the DEA analysis, we found that Michigan greenhouse firms have a poor economic and environmental performance in terms of both production efficiency and energy efficiency scores. Firms could, on average, reduce the use of all inputs by 37% while being able to produce the same amount of output; they could also reduce the use of energy by 45%, which means Michigan greenhouse firms could achieve a significant reduction in both energy cost and CO_2 emissions if the best performing firms' technologies and practices are used.

This study has drawn a richer picture of Michigan greenhouse production with comprehensive information on different aspects of the business, with particular emphasis on energy use and CO_2 emission. However, there are also some drawbacks in this research. The primary problem is we were not able to measure the efficiency of each heating system due to our survey design and sample size of each system. In future research we will address this issue and evaluate the efficiency of different heating systems under different coverings and with different energy types, thus providing more information and insights in firm performance and energy conservation.

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