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Quantifying carbon emissions for a small-scale organic farm in Nova Scotia: What aspects of production contribute the most to the carbon footprint? Are there opportunities for reductions of carbon emissions?

Abstract

Croplands make a significant contribution to global greenhouse gas (GHG) emissions each year and mitigation measures applied to agriculture can aid in reducing these emissions. Carbon emissions from a small-scale organic farm in Nova Scotia, Canada were determined through carbon accounting. Emissions totaled 57.8 tonnes CO_2e, and consisted mostly of emissions from biomass, electricity, fuel and applied fertilizer. Indirect emissions made up 5% of the total. Savings of approximately 2 tonnes CO_2e were quantified from the use of current farming methods of organic fertilizers, lack of pesticides and conservational tillage compared to conventional alternatives. Further reduction opportunities exist with more renewable energy options that limit direct emissions. Further clarification on the place of biomass in carbon accounting is necessary. Organic agriculture has been identified as a potential avenue for mitigation of carbon emissions. This study provides a methodology for further research into agricultural emissions to occur.

Keywords: Carbon Accounting, Agriculture - organic, Carbon emissions

1.0 Introduction

The United Nations Framework Convention on Climate Change calls for the monitoring and mitigation of anthropogenic greenhouse gas (GHG) emissions to reduce the global warming trend (UNFCCC 1992; IPCC 2007; Smith et al. 2008). Croplands contribute approximately 10-12% of GHG emissions each year to the atmosphere (Smith et al. 2007) and thus mitigation measures applied to agriculture can aid in reducing global GHG emissions. Understanding and identifying the sources of GHG emissions, particularly those that are making the greatest contribution in the agriculture sector emissions, will allow for targeted reductions (Smith et al. 2008; Rab et al. 2008; Maraseni et al. 2010).

Carbon accounting identifies the sources of carbon emissions and calculates the amount of emissions produced during a process, or operation (e.g. farming), over a certain time period. Carbon accounting is the methodology of choice for tracking and quantifying emissions, as some industries are required to report their carbon emissions to the government. There is a possibility that agriculture may one day need to report emissions, and thus, a clear methodology outlining which components need to be quantified will be necessary. This study considers the main components of a carbon accounting framework on a small-scale organic farm in Nova Scotia, Canada. The carbon emissions of the farm over the year 2011 was determined, with an additional analysis quantifying possible future reductions as well as the emissions that are already saved with current practices.

1.1 Organic Farming and Carbon Emissions

Agriculture operations emit carbon dioxide, methane and nitrous oxides (Kustermann et al. 2008; Maraseni et al. 2010; Foster et al. 2006). Nitrous oxides and methane emissions have respectively 298 times and 25 times more potential than carbon dioxide to warm the earth (Global Warming Potential) (TCR 2008; Burger et al. 2005; Bouwman et al. 2002a; Bouwman et al. 2002b; Lal 2004a). Organic farming has been growing across Canada as 200 more farms were certified in 2009 compared to 2008, totaling approximately 4000 organic farms (Macey 2010). With the identified mitigation potentials of agriculture (Smith et al. 2008), this is an opportunity to quantify the impact of this growing sector on Canada’s GHG emissions. Organic farming in

Canada requires certification and compliance of the Canadian government standards as no genetically modified seeds, manufactured pesticides nor processed fertilizers can be used (CGSB 2011). It is important to quantify and understand the impact that the growing organic agriculture has on carbon emissions as agriculture could provide an important avenue for reducing emissions globally, of up to 5500- 6000 Mt CO_2e (Smith et al. 2008).

A conversion to organic farming in itself may also play an important role in the reduction of GHG within Canada's agricultural sector. It has been suggested that organic agriculture releases fewer GHG emissions than conventional agriculture (Hillier et al. 2009; Kustermann et al. 2008). Kustermann et al. (2008) examined organic and conventional farms in Germany and found that organic farms released a third of the emissions compared to similar sized conventional farms. These differences can be explained through a range of techniques, which may reduce emissions. Nitrogen emissions can make up the largest contributor to a farm's carbon footprint (Hillier et al. 2009) with inorganic forms of nitrogen releasing more than three times the carbon dioxide equivalent than organic farms. Thus, organic farms have the potential for significantly reduced carbon emissions compared to conventional practices since organic regulations do not allow the addition of nitrogen-based synthetic fertilizers (Maraseni et al. 2010; Hillier et al. 2009; Muller-Lindenlauf 2009; Williams et al. 2006); however, organic fertilizer of animal manure still contributes emissions that need to be accounted (Bouwman et al. 2002b).

Conservation of soil organic carbon, thus reducing soil emissions of carbon, is another aspect where organic farming has a carbon emission advantage over conventional farming (De Gryze et al. 2010; Drinkwater et al. 1995). Agricultural practices, such as tilling the organic layer, can release carbon whereas organic practices promote conservational tillage, or no-tillage, reducing the disruption of the soil organic carbon (Lal 2004b; Smith et al. 2008; De Gryze et al. 2010; Drinkwater et al. 1995). Lastly, organic practices do not allow the use of manufactured pesticides, which are produced in an emission-intensive manner (Lal 2004a).

Although some general organic farming practices may reduce emissions, the overall emissions reductions of organic versus conventional farming may be crop specific. In the United Kingdom, emissions in food production were estimated for specific crops (Foster et al. 2006; Kustermann et al. 2008. Specifically, Foster et al. (2006) found that organic tomatoes used 1.9 times more energy than non-organic tomatoes and Kustermann et al. (2008) found fewer emissions for conventional methods of growing winter wheat. These reduced emissions were explained due to the increase yields from conventional methods, as the energy inputs are more divided among increased produce; however, with all emissions aggregated, organic farms still had lower absolute emissions (Kustermann et al. 2008). With a lack of consensus and a growing agriculture sector, including both conventional and organic farming, there is a need for further research that will continue to inform the debate.

1.2 Carbon Accounting in Agriculture

Carbon accounting is a process used to quantify these emissions in agriculture and identify potential options for reducing emissions (Maraseni et al. 2010; Hillier et al. 2009; Foster et al. 2006; Kustermann et al. 2008; Smith et al. 2008). Carbon accounting quantifies the emissions of six major greenhouse gases as determined by The Kyoto Protocol (1997): carbon dioxide; methane; nitrous oxide; hydrofluorocarbons; perfluorocarbons; and sulfur hexafluorides (TCR 2008). The latter three gases are not produced in an agricultural context (Maraseni et al. 2010). Carbon accounting has gained momentum globally through The Climate Registry (TCR), World Resources Institute (WRI) and IPO 14000 series as a set of standard methods to quantify carbon emissions (TCR 2008; Maraseni et al. 2010).

The procedures used for carbon accounting are broadly separated into direct emissions and indirect emissions (also called Scopes/Tiers 1 and 2; 3 respectively) (Maraseni et al. 2010; TCR 2008). Direct emissions are produced through farm operations, such as tillage, the combustion of fuel, and the production of electricity. This category of emissions would be reported to the government, if indeed organic farms were mandated to do so. Indirect emissions are not produced from the actions of the farmer but instead, incorporate the emissions created from the production of an item that is used on site, for example, the production of machinery. The manufacturing company would be obligated to be report these emissions and not the farm that uses the equipment. Thus, there is a benefit to keep these components separate from indirect emissions, which are not as immediately applicable to the farmer. Within indirect emissions, there are the emissions that occur upstream and downstream. Upstream emissions occur prior to the farm, and would include the production of machinery and other goods. Downstream emissions would occur after the production on the farm and would include the transportation of customers to the market.

There are still significant methodological issues relating to carbon accounting, for both direct and indirect emissions. Direct emissions may have standard methodologies each with specific emission factors for fossil fuel combustion (TCR 2008) applied fertilizer (Hillier et al. 2009) and tillage (Lal 2004a); however, there is no universal agreement over how to incorporate offsets such as renewable energy use, and whether biomass is considered carbon neutral (Finkbeiner 2009; Maraseni et al. 2010; Johnson 2009; Cherubini et al. 2011). There is a movement to quantify emissions from biomass, including them under direct emissions; however this is still a controversial method at odds with the IPCC (2006) guidelines (Johnson 2009). An additional aspect of direct emissions is emissions from soil. Soil emissions have been quantified separately (Hillier et al. 2009; Lal 2004b), but not in a carbon accounting context that incorporates soil emissions with an entire farm's emissions (Drinkwater et al. 1995; De Gryze et al. 2010; Burger et al. 2005).

Indirect emissions, which should be core to carbon accounting, are still debated (Finkbeiner 2009; Pandey et al. 2011) as there are many aspects to indirect emissions that simply have not yet been articulated in an agriculture context. One example is transportation, where emissions from shipping (Leonardi & Baumgartner 2004), sometimes referred to as food miles, are not new (Foord 2010). Food miles vary depending on the mode of transportation, and increase with the distance (Foord 2010). Emissions from shipping have not been applied to agriculture inputs. Some standards have been articulated in carbon accounting studies, such as the incorporation of machinery (Maraseni et al. 2010); however, these indirect emissions are not quantified consistently. Among these issues, defining boundaries for farm operations for both conventional and organic farms remains unclear (Maraseni et al. 2010). These gaps, however, are important opportunities to clarify and strengthen carbon accounting (Finkbeiner 2009; Pandey et al. 2011).

The variety of studies looking at carbon accounting in agriculture has made many advances in the field, despite the methodological limitations previously outlined. Not all crops have the same carbon burden, thus analysis should be conducted per crop (Foster et al. 2006), or on a whole farm basis (Kustermann et al. 2008). Electricity has also been identified as a major component of agriculture carbon accounting totals (Foster et al. 2006; Maraseni et al. 2010). Soil emissions have been extensively quantified, and determined to be an important contributing factor to indirect emissions (Kustermann et al. 2008; De Gryze et al. 2010).

Potential improvements still exist within the carbon accounting framework used to quantify indirect emissions from agriculture as well as direct emissions, such as biomass. Past agricultural studies examining carbon emissions have not always distinguished between organic and conventional agriculture (Maraseni et al. 2010), where differences can be significant (Hillier et al. 2009). If they did, the focus was limited to specific crops (Foster et al. 2006) or a specific aspect of organic farming, such as fertilizer emissions (Hillier et al. 2009). Studies have examined a range of locations: Australia (Maraseni et al. 2010), the United Kingdom (Foster et al. 2006), Germany (Kustermann et al. 2008) and Scotland (Hillier et al. 2009); however studies in North America remain limited. Most importantly, each study includes a different set of indirect components, and thus there are no definitive guidelines for what to include when assessing indirect emissions from agriculture.

1.3 Proposed Research

Here I propose to estimate the carbon emissions for a small-scale organic farm in Nova Scotia through carbon accounting procedures. The organic farm is in Nova Scotia, Canada and grows a variety of crops with the focus on greenhouse-grown tomatoes. This farm is one of approximately fifty organic farms in Nova Scotia (Macey 2010), and thus the results from this study can be easily disseminated to other similar farms in the province. The study will be addressing the following three research questions.

1.3.1 Research Questions

1) What aspects of production on the farm contribute the most to the carbon emissions?
2) What are the key components that should be included in accounting procedures with respect to the possibility of future carbon reporting?
3) What opportunities exist to reduce greenhouse gas emissions on the farm?
4) What practices are currently reducing emissions compared to conventional alternative methods?

1.3.2 Objectives

This study will determine appropriate methods and consideration for indirect emissions, and then will quantify the carbon emissions for the organic farm. The key objectives of this study are:

1) To estimate CO_2e emissions from the organic farm over the year 2011 and to determine which aspects are the major contributors to the total emissions on the farm,
2) To determine key direct and indirect emissions components for inclusion in the carbon accounting framework,
3) To identify opportunities for emission reductions on small-scale organic farms based on results from Objective 2, and
4) To carry out a comparison of current practices to other conventional methods.

2.0 Methods

This study determined key components of indirect emissions on a small-scale organic farm, and estimated the total emissions during the year 2011.

2.1 Study Location

Most of Nova Scotia has a modified continental climate, due to the proximity to the ocean, and the growing season in Nova Scotia ranges from 190 to 210 days (Phillips, 1990). The farmer owns 46 hectares, of which 3.5 is farmed area (42 ha is forest, 3.5 ha cultivated and 0.5 ha is the farmstead). The farm has six greenhouses. Produce is a variety of vegetables, with cherry tomatoes as the largest crop (22% of sales) and Mesclun salad mix as the second largest crop (17% of sales). Other crops include vegetables such as mushrooms, potatoes and carrots.

2.2 Study Design

A small-scale organic farm in Nova Scotia was selected by the researcher based on the farmer's willingness to share information and data. Carbon dioxide, methane and nitrous oxides were the three gases quantified as they were determined to be the only Kyoto Protocol designated gases produced in farming (Maraseni et al. 2010). Global Warming Potentials (the radiative forcing that occurs over a 100-year time period) were used (298 and 25 for nitrous oxides and methane respectively) allowing for conversion to tonnes of carbon dioxide equivalent (t CO_2e) standard (TCR 2008).

2.2.1 Determining Indirect Factors

In order to determine the indirect emissions components, data was collected from farming components that:

1) Were identified by the farmer

2) The farmer had control over the component (This is essentially a focus on upstream indirect emissions, that occur prior to the farming procedures, and not downstream)

Discussions with the farmer determined the major inputs for the farm that are applicable for consideration in this case study (Table 1). All of the components that the farmer controlled were selected from the list. Existing studies that investigated organic or conventional farming along with carbon accounting were analyzed and compared with the farmer's description of the operations at the case study farm. These combined methods provided support that all applicable aspects of organic farming are included for analysis, meeting objective 1.

Table 1 List of data that was collected by the farmer.

Direct Emissions			
Category	Farming Procedures	Recorded Information	Components
Fuel used	Transportation, machinery work with tractor, harvesting wood, tillage	Gasoline and Diesel amounts used, recorded from fuel purchase receipts	Diesel tractor; Gasoline truck, chain saws, woodsplitter, rototiller and lawnmower
Biomass	Heating greenhouses	Species of Tree, amount harvested in cords recorded at time of harvest.	
Electricity Use	Refrigeration, irrigation	kWh from electricity bills	
Fertilizer	Application to enhance growth of vegetables	Type of products, amounts, storage details, and details of application	emissions from application,
Soil Emissions	Tillage of soils in greenhouses and in crop beds.	Area tilled recorded, and type of tillage used	Conservation and conventional tillage are used.
Indirect Emissions			
Transportation of Fertilizer	Transportation of fertilizer to the farm	Type of products, location sourced from, amounts, method of transportation,	Transportation of fertilizers,

Transportation of Seeds	Transportation of seeds to the farm.	Type of seeds, amount, location sourced from and method of travel	Only seeds accounted for.
Capital Goods	Production of capital goods.	Make and model of capital goods recorded; Information sourced from the manufacturer.	Greenhouses, machinery

2.2.2 Carbon Accounting

A compilation of existing methodologies for carbon accounting was used to quantify carbon emissions on the organic farm in Nova Scotia (Table 2). The Carbon Registry's (TCR) (2008) methodology for direct emissions and the corresponding emission factors was utilized in this study for fuel (diesel and gasoline) (TCR uses Scope 1, Scope 2). TCR is one of many different, but similar, accounting protocols, such as World Resource Institute, and the ISO 14000 series and was selected based on its level of appropriate detail. The ISO standards, for example, have to be purchased, which is not necessary for this context. Biomass values were calculated with the TCR method, but with tree species-specific emission factors from the Millennium Institution (2011). For organic fertilizer emissions, this involved determining nitrogen content (Stout 1990) then using emission factors for energy involved in the creation of fertilizer (Stout 1990) and from application of emissions (Hillier et al. 2009). Aluminum production also emits tetrafluoromethane, which is a GHG. It was not included and considered outside the scope of this study (Table 2). These procedures were based off of a variety of studies (see section 2.4). Previous studies examining agriculture emissions developed case specific methodologies based on the specific components that were investigated. A similar approach for this research was used.

Table 2 List of emission factor used in the analysis.

Process	Factor (kg CO_2e / unit)	Source
Direct Emissions		
Fuel	Diesel 2.689 kg CO_2/L Gasoline 2.311 kg CO_2/L	(TCR 2008)
Electricity	0.828 kg CO_2e / kWh	(NS Power 2010)
Tillage	15 kg/ha for rototiller 8 kg/ha for spading	(Lal 2004a)
Fertilizers	Application: 10.413 kg CO_2e / kg Energy: 0.0275 kg CO_2e / kg N	(Hillier et al. 2009; Stout 1990)
Biomass	Species specific MMBTU / cord 93.87 kg CO_2/ MMBTU	(Millennium Institution, 2012) (TCR 2008)
Indirect Emissions		
Seed Transportation	0.096 kg CO_2 / tonne-km	(Leonardi & Baungartner 2004)
Fertilizer Transportation	0.096 kg CO_2 / tonne-km	(Leonardi & Baungartner 2004)
Machinery*	23.25 kWh/kg 0.828 kg CO_2e /kWh	(NS Power 2010; Maraseni et al. 2010; Stout 1990)
Greenhouses*	Aluminum: 1.5 kg CO_2 / kg Galvanized Steel: 2.9 kg CO_2e / kg	(Weston 1995; Bolin & Smith 2011)

*Capital goods emissions were amortized over the life of the product.

2.2.3 Boundaries

The study was divided into three stages: the emissions to create the materials used on the farm (indirect); the emissions during farm operation (direct); and the transportation of produce to market (indirect). For a component to be quantified, it must fit into one of these categories (e.g. customers driving to the farm to buy produce were not included). These boundaries were determined through discussions with the farmer, and supported through literature (Yuttitham et al. 2011).

Nitrogen was determined to have the largest impact from fertilizer (Hillier et al. 2009). Thus, quantification of emissions from application was limited to nitrogen emissions.

2.2.4 Data Collection

Once the direct and indirect emissions were determined for inclusion in the study, the farmer was asked to record all relevant data for 2011. The farmer recorded data for direct amounts of electricity, biomass, fuel data and fertilizers from January 1 to December 31 2011 (Table 1). The farmer also supplied descriptions of the indirect emissions processes from January 1 to December 31 2011 (Table 1).

2.3 Analysis

An analysis of the current farming methods was undertaken to find conventional alternatives that could have been used instead. The emissions were then calculated for the conventional alternatives to see if there were emission savings from using current organic methods. Comparisons were made between: biomass, propane and fuel oil; organic fertilizers and inorganic varieties; human labour and pesticide use; conservational methods to conventional methods of tillage, and; shipping produce from Ontario to Halifax.

The total biomass used was converted first into energy (MMBTUs to GJ) (Millennium Institution 2011) and then that energy value was converted to amounts of propane, light and heavy fuel oil, three typical methods of heating greenhouses (TCR 2008). Then, using TCR

(2008) emission factors for the combustion of those fuels were the alternative emissions able to be determined (Table 3).

Table 3 of Emissions Factors for Biomass from TCR (2012).

Alternatives	Energy Content: (GJ/KL)	Emissions kg CO_2 / L
Propane	25.310	1518
Light Fuel Oil	38.8	2873
Heavy Fuel Oil	42.5	3127

Nitrogen content in the manure was estimated at 0.48% (Stout 1990). Other fertilizers (potting soil, fish feed, seaweed) had the nitrogen content provided. The total amount of nitrogen was multiplied by the emissions factor for fertilizer application emissions (9.46 kg CO_2e/kg of active ingredient) which had been converted to carbon dioxide equivalents from Hillier et al. (2009) by multiplying (44/12). The energy cost to produce the inorganic fertilizers was compared as well, with a factor of 4.77 kg CO_2e/kg of AI (Hillier et al. 2009).

In order to estimate emissions from the use of pesticides, a farmer in NS using conventional methods on a similar size plot was approached for information. Thus, one insectide (Admire) and one herbicide (Treflan) that the farmer described using were quantified as an appropriate alternative for comparison to an organic farm. Ranges of application differ depending on the pest and crop, or soil type for the herbicide (Admire: 200 ml/hectare to 1.3 litres/hectare; Treflan: 1.2 to 2.4 L/hectare); thus, the lowest values of the applications were utilized for calculations, as this would be the minimum emissions savings an organic farmer could consistently see. Emissions factors for agro-chemical production were utilized from Maraseni et al. (2010) of 18.7 kg CO_2e / kg insecticide and 23.1 kg CO_2e / kg herbicide.

The conventional tillage methods that could be used were identified through discussions with the farmer, and then emissions calculated with values from Lal (2004b) once they were converted into CO_2e from carbon equivalent. Conventional tillage would utilize one round of plowing (55 kg CO_2e/ha), followed by two rounds of light disking (29.3 kg CO_2e/ha) as the method for secondary tillage.

Shipping distances was the final comparison, looking at the difference between ground shipping from Toronto to ground shipping in Nova Scotia. Ontario is one of the four main producers for Nova Scotia's imported tomatoes (the largest crop of the farmer). The others are Mexico, Florida and California. Ontario was chosen because of the most similar growing climate to Nova Scotia, and Toronto as the proxy city as most Ontario-based shipping at some point travels through Toronto.

The last component was a sensitivity analysis for biomass. This investigates other methods of quantifying the same emissions to determine how variable the value might be. Such a comparison was conducted for biomass, as it was the largest component. Thus, it was important to see how accurate the method was. An alternative approach was utilizing TCR (2008) procedure based from incomplete combustion and the efficiency of the furnace used. The cords consumed were changed to kg (1324 kg/ cord) and two efficiencies of 50% (500 g CO_2/kg) and 75% (750 g CO_2/kg) were utilized to calculate emissions (TCR 2008).

2.4 Limitations

This study is confined to one case study of a small-scale organic farm in Nova Scotia and thus, is not representative of all small-scale farms in Nova Scotia. However, the results may lead to best practices that can be extended to the industry. There are also compounding effects from the small-scale nature of the study farm. Typically, small-scale enterprises usually have higher costs than larger enterprises. Farms are no exception. Thus, due to the small-scale nature of this study, the carbon costs are compounded.

A second limitation was the scope of the study. Carbon sequestration and offsets were not quantified. Waste crops are used as manure on the farm; since these products come from on-site and decompose on-site they were classified as carbon neutral. Thus, any waste crops will not be quantified. An additional focus is on upstream indirect emissions, because they can be altered and ultimately reduced by the farmer. The study includes transportation of crops to market by the farmer, as it could not be separated from the fuel use of the truck. After that point, no further downstream emissions will be included.

A third limitation comes from the use of emission factors. It was not possible to measure emissions from the farm directly, thus emission factors were the most appropriate and scientifically robust alternative. Emission factors are averages, thus each has a variability associated with the value. Most of the quantifications using the TCR (2008) values are classified as Tier C, which means that they have the highest variability. It was not possible to have less variability, unless direct measurements of emissions were taken.

Some emission factors were drawn from sources, where the value was not necessarily utilized for carbon accounting in an agriculture context. The TCR (2008) is a broad methodology that is applicable to all industries because it is so broad. There were some components that needed more specificity. For example, Millennium Institution's values on energy per species of tree are limited because it is not scientifically published data; however, these factors were calculated from direct combustion of tree samples to quantify the energy. The location, Ontario, also provided the closest comparable measurements to Nova Scotia with the same tree species utilized. Every effort was made to use emission factors that matched most closely the use in the current study. Thus, each emission factor was compared and selected because it was best available value, although there are limitations with each choice.

There are limitations to carbon accounting in general based on how far back into the life cycle assessment (LCA) of a fuel one goes. In this study, the energy used to produce fertilizer was counted as part of the emissions from fertilizer, and is generally standard practice (Hillier et al. 2009; Maraseni et al. 2010; Lal 2004a). However, with TCR (2008) the direct combustion of gasoline and diesel is considered, and not the emissions from the energy in extracting and processing the oil. In this study, the LCA of gasoline and diesel was not considered, following standard practice (IPCC 2006; TCR 2008). There is a possibility for future research to undertake a full LCA of all the components used on the farm.

Lastly, climatic variation is not expected to have an effect on operational changes and thus the emissions are not expected to change from year to year solely due to weather.

3.0 Results

The final components that were quantified as direct emissions were: fuel; electricity; biomass; emissions from applied fertilizer in the form of nitrous oxides, and; emissions from tillage. Indirect emissions were quantified from: the transportation of seeds; transportation of fertilizers; emissions from the production of machinery, and; emissions from the production of the greenhouses (Figure 1).

Emissions on the farm totaled 18.6 tonnes CO_2e/ha (27.0 tonnes CO_2e absolute) for the year 2011 not including a biomass value of 30.9 tonnes CO_2e (Figure 1). Including biomass, the respective figures doubles to 57.9 tonnes CO_2e (Figure 1; Appendix C).

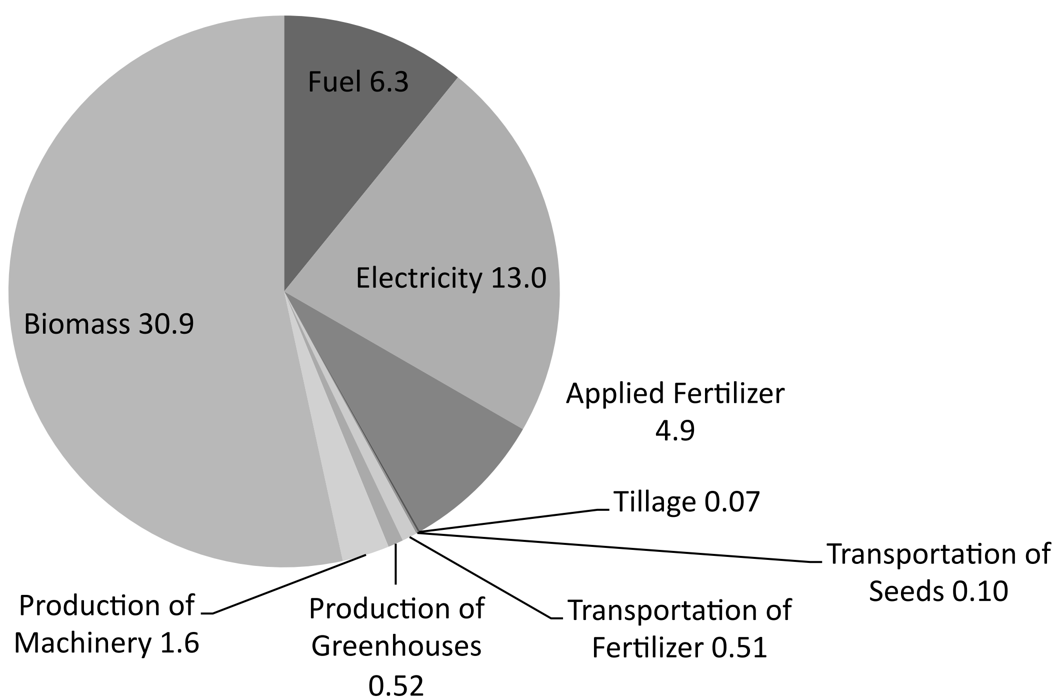

Figure 1: Emissions including biomass totaling 57.8 tonnes CO2e.

Direct emissions including electricity, fuel, and applied fertilizer were the largest proportion of emissions accounting for nearly 95% of total emissions (Figure 2).

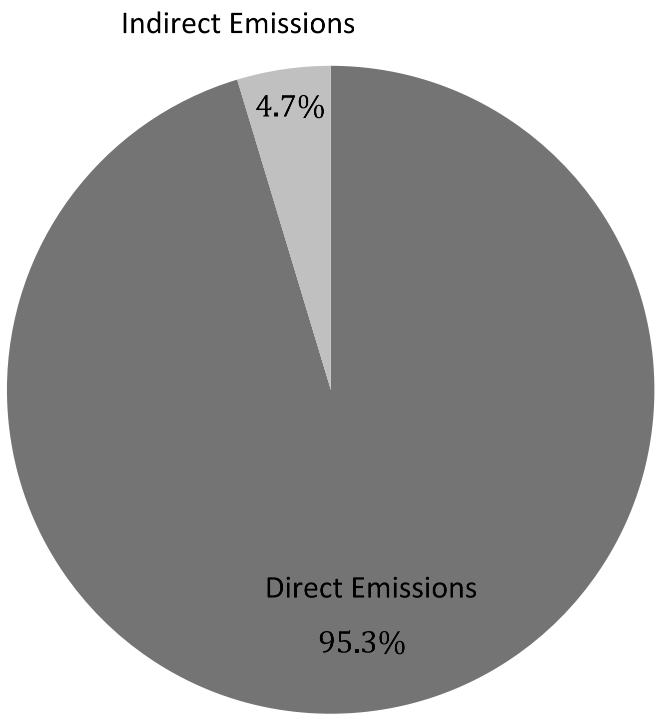

Figure 2 A comparison of direct and indirect emissions and their respective contributions to the total emissions (tonnes CO2e).

Indirect emissions totaled 5% of the total (Figure 1; Figure 2). Of the indirect emissions, the production of machinery made the most significant contribution, with transportation of seeds being nearly negligible (Figure 3).

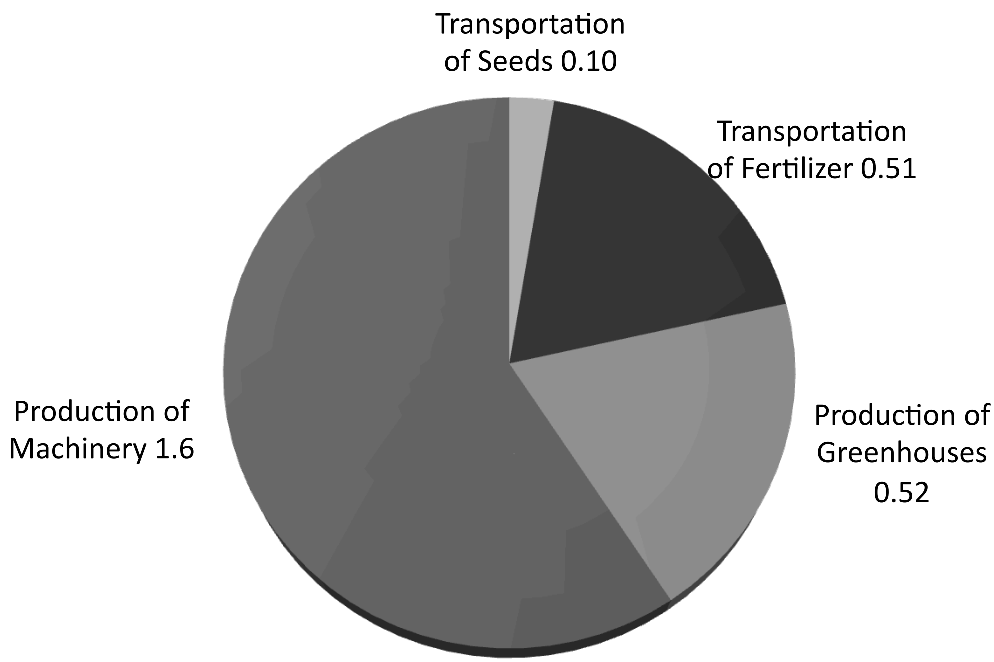

Figure 3: The breakdown of indirect emissions. Production of machinery is the largest component. Indirect emissions total 2.7 tonnes CO_2e.

3.1 Savings Due to Current Methods

Several farming methods used on the case study farm were compared to conventional alternatives. These include: biomass to propane and fuel oil (Figure 4); organic fertilizers to inorganic fertilizers; lack of pesticides to pesticide use, and; conservational (organic) methods of tillage to conventional methods (Figure 5). Alternatives to biomass were quantified in terms of fuel oil and propane emissions, the two typical alternatives used to heat greenhouses. These fuels reported fewer total emissions than the biomass values. Emissions from pesticides and tillage are a fraction of the emissions totals.

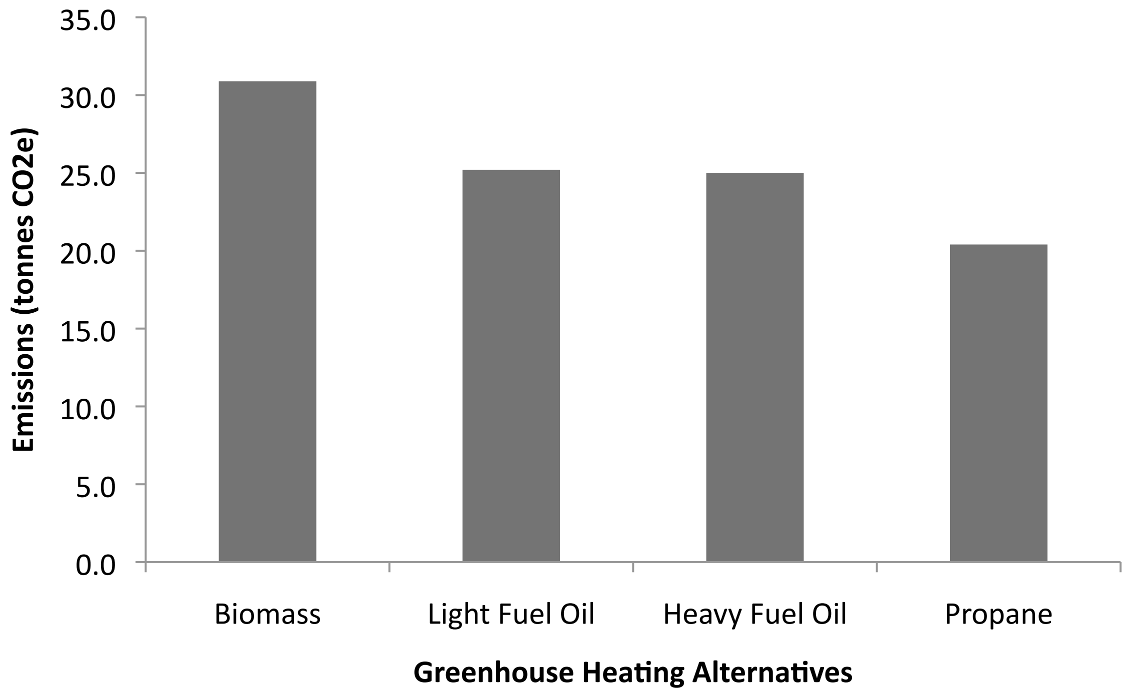

Figure 4 The emissions from biomass, the current method of heating greenhouses to three conventional alternatives.

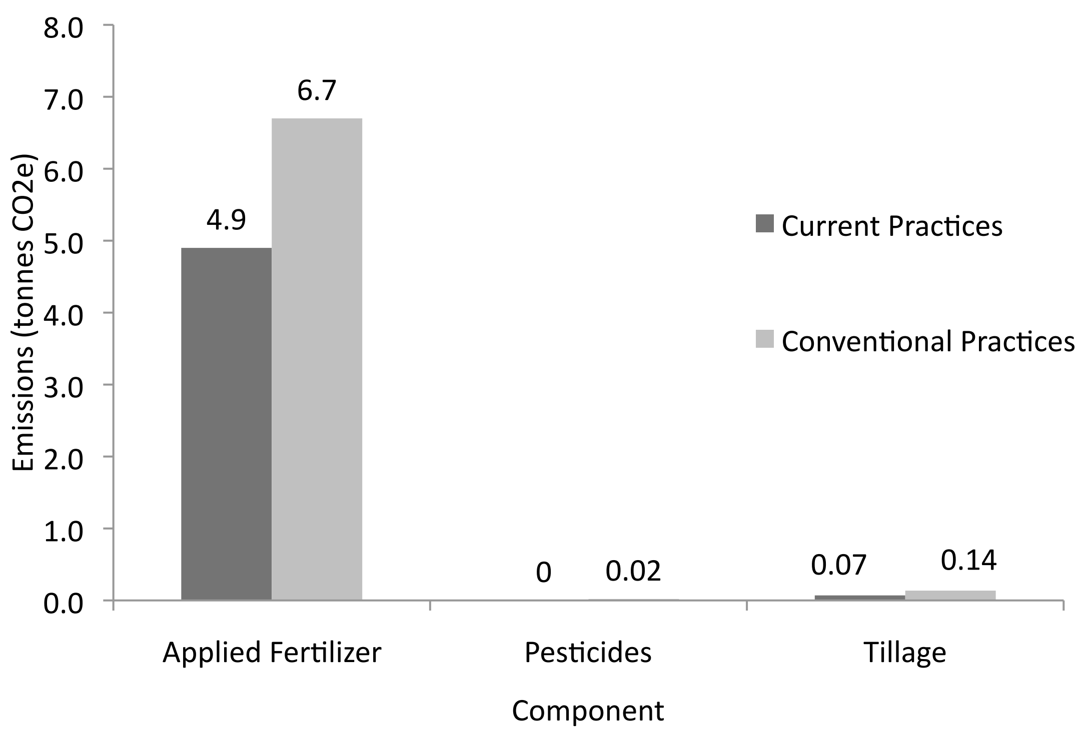

Figure 5 Comparison of emission savings between current organic methods and possible conventional alternatives.

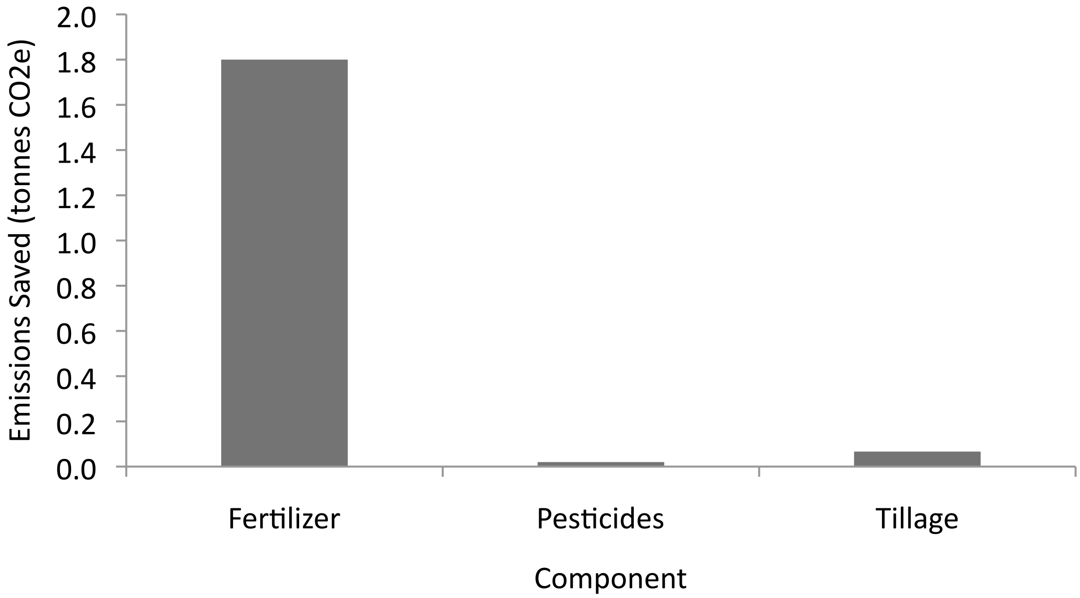

Figure 6 The difference in emissions between conventional alternatives and the current practices. The amount saved for current practices is shown.

Emissions from current practices were less that the conventional practices, except for biomass, which emitted more than the three alternatives (Figure 4; Figure 5). Total savings came to approximately 2 tonnes (Figure 6).

The last comparison was made between emissions from shipping produce from Toronto to Halifax, compared to shipping produce within Nova Scotia. Produce via Toronto emitted 0.017 tonnes, whereas produce from within Nova Scotia emitted 0.0019 tonnes, differing by a factor of ten.

3.2 Biomass Sensitivity Analysis

The sensitivity analysis conducted used two efficiency values that were the estimated extremes of furnace efficiency on the farm, which were 50% and 75%. These efficiencies resulted in biomass emissions of 11.3 tonnes CO_2e and 16.9 tonnes CO_2e respectively.

4.0 Discussion

Electricity use was the largest component of direct emissions, followed by fuel combustion and then applied fertilizer. Electricity was hypothesized to be one of the leading contributors (Maraseni et al. 2010) since electricity and biomass were the two main sources of energy inputs for the farm, it was expected that their emissions would be significant. Other studies, such as Maraseni et al. (2010) also found a high component of electricity (65% of the total emissions) mostly due to irrigation and post-harvest activities (refrigeration, cleaning) combined.

Irrigation is not the main electricity source for Nova Scotia and the electricity values are lower as a result. Australia uses 18.05 km^3 $year^{-1}$ of water for agriculture, whereas Canada uses 5.4 km^3 $year^{-1}$ for agriculture (CIA World Factbook 2012). The level of agriculture is comparable* between the two regions with similar crops, however Australia uses around three times more water for irrigation. Maraseni et al.'s electricity value is 65% as opposed to this study's value of 11%.

Instead of for irrigation, the farm in this current study uses electricity for other components such as refrigeration and lights aiding seed germination. The largest electrical drain is from refrigeration, mostly during the summer months. Additionally, the use of lights to germinate seeds indoors may be unique. Thus, the electrical consumption on the farm would be similar to Maraseni et al.'s (2010) after-harvest processing category, due to the lack of significant irrigation. In fact, Maraseni et al.'s (2010) post-harvest energy is very similar to this

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* Agriculture in Australia produces USD $110 billion each year and Canada's level of agriculture is similar, totaling USD$ 115 billion each year (CIA World Factbook 2012).

study's electricity values (11%; 10.9% respectively). Thus, electricity is a large component in both studies relative to other emissions components; however the magnitudes are different compared to each other. Australia uses much more electrical energy, due to the lack of electricity needed for irrigation in Nova Scotia.

Lastly, emissions factor for electricity makes a difference in the comparative size of the component. The emissions factor used in the present study came from the 2010 value from NS Power, direct from the production source. Maraseni et al. (2010) use a wide variety of emission factors for the different states varying from 37 to 364 k CO_2/GJ of energy. Australia uses coal-generated electricity, but some states had very high levels of hydropower, which, as a renewable energy, has a low emission factor (Maraseni et al. 2010). Thus, the high emission factor for Nova Scotia due to the use of coal-generated power likely increased the emissions from electricity.

Applied fertilizer on the farm totaled 4.9 tonnes CO_2e, 3.4 tonnes CO_2e / ha, which is significantly larger than other studies (Table 5). Hillier et al. (2009) calculated that organic farms in Scotland produced 208 kg CO_2e/ha/yr through mechanical operations on the field and nitrous oxide emissions from fertilizers (Table 5). The current study used Hillier et al.'s (2009) method, however, included fewer components in the analysis and the results of the current study still showed increased emissions per hectare. Kustermann et al. (2008) calculated a value of 744 kg CO_2e per ha, which consists solely of nitrous oxide emissions, like this study. The authors discuss how soil conditions can contribute to high or low nitrous oxide emissions, which could explain some of the differences seen here. The current farm under study reclaimed an area that had been a grass lawn for the farm. The soil in this context would have much lower nutrient levels than other farms studied that had been in operation for decades (Kustermann et al. 2008). The Nova Scotia farmer is applying significant amounts of fertilizer to bring the soil nutrients back to typical levels. Thus, soil history and the amount of applied fertilizer are likely the main differing factors between these results and the literature. It would be expected that these emissions would decrease as the soil nutrients are built up.

Table 5: Comparison of total value among current estimates.

Study	**CO_2e/ha**	
Kustermann et al.	744 kg	Solely Nitrous oxides emissions
Hillier et al.	208 kg	Included mechanical operations on fields, and emissions from applied organic fertilizers.
Current Study	3.4 tonnes	Emissions from four types of organic fertilizers.

The lack of emissions from tillage was consistent with Hillier et al. (2009); however, it had been expected to contribute more. Soil is a large carbon sink (Lal 2004b) and there are numerous studies that have quantified the mitigation potential of changing from conventional tillage to conservational tillage (Lal 2004b; Smith et al. 2008). Thus, because of the emphasis on tillage in past studies, it had been hypothesized that tillage would be a significant component of total emissions. These results have shown that when aggregated, tillage is an important factor; however, on one farm it was not a major component (Figure 1). One factor may simply be scale, and that at a large scale, with all farms pursuing a form of tillage, the emissions are a much larger component than for one farm of 1.45 ha. One concern is that the emission factors utilized include fuel used by the tilling machinery into the factor. Since this study quantified fuel use separately, this may involve some double counting. This may be a gap in the literature, as many previous studies suggest drawing from these factors (Maraseni et al. 2010; Hillier et al. 2009). Thus, even with the possible double counting, tillage was the smallest component (0.07

tonnes; 0.1%) with little to no impact on the overall emissions total. This highlights an area in need of improvement for consistent methods in carbon accounting, either by isolating emissions from soils only, or being able to separate out the fuel used by the tillage component of the total tractor fuel emissions.

In the present study, biomass was used to heat six greenhouses and thus it was thought that this would be a significant source of energy. As expected, biomass had the largest absolute value of emissions; however, some procedures are unclear whether biomass should be counted as a fuel or treated as carbon neutral (Johnson 2009). Biomass is used as a source of energy, however within an IPCC standard procedure it is quantified as part of land use, land use change and forestry (LULUCF) (IPCC 2006). This does not clearly reflect the use of biomass. Many studies calculate biomass separately from other sources of fuel (TCR 2008) or as carbon neutral; in a review of literature, Johnson (2009) found that only one out of twenty-five researchers did not assume biomass was carbon neutral, as the prior uptake of carbon in is thought to equal carbon out during combustion. This concept does not adequately address the time-span, as the sequestration of carbon that offsets the combustion occurs over hundreds of years of growth (Cherubini et al. 2011); nor does it adequately address the decrease of the carbon stock, since there is arguably a fundamental difference between a standing forest that sequesters carbon and wood as fuel (Johnson 2009). Thus, there is a movement to quantify emissions from biomass, including them under direct emissions, and to address the decrease in the carbon sink that occurs with the combustion (Johnson 2009). For this project, burning biomass for heat was the greatest contributor to the farm’s carbon emissions as an energy source and thus, it was calculated and reported as part of the footprint (Johnson 2009; Cherubini et al. 2011).

The corresponding amount of propane, light fuel oil, and heavy fuel oil in lieu of biomass was calculated. Each came out with fewer emissions than using biomass (Table 4), which would suggest that fossil fuels are the best option for reducing carbon emission. Johnson (2009) calculates that with his proposed method of addressing the loss to the carbon sink, emissions from biomass can be as much as two times higher than from natural gas. The methodology needs to be clarified further; sustainable methods of local biomass harvesting are on a very different time-scale than fossil fuels, due to the ability to regenerate and sequester carbon faster. Some biomass users, such as this farm, that are practicing sustainable harvesting methods on a small scale and are working to ensure re-growth and continual sequestration will be at a carbon-disadvantage. Even if the heating alternatives quantified may have had reduced emissions, it does seem more self-sustaining for the farmer to continue with biomass harvesting.

The method chosen did include biomass as a component and quantified the emissions. Values from the Millennium Institution (2011) of energy per tree species were utilized, along with TCR (2008) emission factor. While these values were not scientifically published information, the values had been determined from combusting specific tree samples for each species in a furnace (Millennium Institution 2011). Thus, these values were more accurate than the average combustion efficiencies utilized by TCR (2008), which does not differentiate species of tree (they are all included) nor location. The TCR (2008) approach was utilized for the sensitivity analysis.

A sensitivity analysis was performed on the biomass values to determine a confidence with the current emission factors. This was to be done with the suggested values from TCR

(2008) and instead of 1 (perfect combustion) suggested by TCR (2008) two values of 50% and 75% were utilized. It is likely that the actual efficiency would fall somewhere between these two values. These resulted in emission totals of 11.3 and 16.9 tonnes respectively. These values are indeed different from the current estimate; however, the values used do follow TCR (2008) protocol, with tree species-specific energy content values. Quantifying emissions from biomass could be clarified with either:

1) Species information based out of Nova Scotia, or

2) Weighing the biomass used, and determining the efficiency of the furnace.

The first would allow for a more accurate value with the method used in this study. The second would allow for the sensitivity checks, which followed the TCR (2008) general protocol to be more accurate.

Some concerns could also be raised with respect to the transportation categories. Some seeds are delivered through the farm truck, and thus, these seeds were not included as an indirect emission. Instead, the fuel use was included as a direct emission. Additionally, transportation of produce to market in the truck was counted as a direct emission because it could not be separated from the fuel used. In reality, this would be considered as a downstream indirect emission and thus should be outside the scope of the project, if it were not for the fact that this falls within the farmer's control (see section 2.4). While unlikely to make a different among the direct and indirect totals (the transportation values were small at 0.07 tonnes CO_2e), these circumstances highlight the complexity of the categories and the inconsistencies that can arise when attempting to assign emissions to specific categories.

The emission factor that was used for transportation of seeds and food to market was an average value taken from Leonardi & Baumgartner (2004) a German study. This was the most reliable average value published in a scientific journal, and Canadian equivalents were unavailable. Interestingly, transportation made only a minor contribution to the overall footprint (Figure 1; Figure 3). This study would suggest that any focus on food miles would be overstated due to its size and reduced relative importance in the whole footprint. Seeds were sourced from across North America, yet emissions still made up such a small proportion to the overall footprint (from Toronto – 0.017 tonnes CO_2e). From a carbon standpoint, emissions saved during production in a warmer climate, for example, could easily outweigh the increased transportation emissions. This would make an interesting comparison for future research.

Based on the result from the current study, the major indirect emissions components that should be quantified in a footprint analysis are production of machinery, greenhouses, and lastly the transportation of various materials. These components were crafted from the inputs that were brought onto the farm: tractor, greenhouses, and necessary materials for crops (seeds, fertilizer). Other farms may have different inputs. The scope of the study was limited to indirect emissions that related to the farmer so downstream emissions, save for transportation of produce to market, were not calculated. This was the focus to ensure relevancy to the farmer, as the farmer can make decisions based on carbon emissions for future years.

4.1 Current Emission Savings

Four different aspects were compared between conventional and current organic methods of farming. Interestingly, although the organic emissions were much lower for tillage and pesticides (Figure 3), the absolute values of these savings (0.16 tonnes CO_2) are only 0.6% of total emissions on the farm. Thus, while these organic methods are important to adhere to for organic labeling and other environmental benefits, these savings are not a significant reduction in carbon emissions. An important point to note with the amount of pesticides assumed in this study is that the comparison in the study used the lowest range of amount applied and also only looked at one application. Thus, these savings could increase each year depending on the number of times a conventional farmer applied the different agrochemicals. Additionally, these savings would occur every year that current organic methods are adhered to. The organic alternatives for pest control are generally human labour and time intensive, which is not measured in carbon footprints.

One clear emission saving method on the farm was the use of organic fertilizers instead of inorganic ones (Figure 3), which are more energy intensive to produce. This resulted in savings of 1.8 tonnes CO_2e per year. The last comparison was with biomass and alternatives. Although not a requirement of organic farming, it can be considered a more sustainable energy option for this specific farm. Interestingly, the alternatives had lower emissions totals. This does not take into account, as mentioned, whether or not the biomass is harvested sustainably. If not, this could have detrimental effects on the forest ecosystem. The LCA of the fossil fuel alternatives is also not taken into account. It would be expected that if a full LCA were attempted, biomass emissions would be reduced in comparison.

Following organic regulations means saving around two tonnes CO_2e per year through organic fertilizers, organic methods of pest control and alternative tillage methods. This would result in emissions totals that are less than conventional farms, in terms of absolute values.

Foster et al. (2006) determined that organic farms, especially with controlled environments such as greenhouses, have higher emissions per unit of produce. This is because the carbon demands of a controlled environment, eg. heating, are more distributed with higher yields from conventional methods. Thus, while organic farms may have lower absolute emissions, the lower yields of some organic crops may make them more carbon intensive per unit of produce than crops produced by conventional means. Kustermann et al. (2008) found that the same holds true for certain crops in Germany; however, once all the crops are taken into account, organic farms still have a carbon advantage emitting 263 kg CO_2e /Mg of produce as opposed to 376 CO_2e / Mg for conventional farms. This is one opportunity for further research to see if Kustermann et al.'s overall carbon advantage holds true for organic farms in Nova Scotia through research directly comparing carbon footprints of organic and conventional farms in Nova Scotia.

Emissions from ground shipping (the method used for calculations in this study) will increase with distance and the larger the weight of the freight. Tomatoes, the largest produce from the farm, are also imported to Nova Scotia from Mexico, Florida, California and Ontario (Foord 2010). As the results have shown, transportation is a small component of the total emissions for production on this farm (Figure 1). Shipping from Ontario, a distance of 1743 km, was a factor of ten larger than shipping within Nova Scotia. This value (0.017 tonnes), however, is 0.03% of the total footprint on the farm. Thus, this study would suggest that ground shipping may contribute insignificantly to the carbon emissions of food production. If food production in another location were to be slightly less carbon intense, there would be the ability to ship produce nearly halfway across the country without impacting carbon. The food miles concept, while important, may need to expand and include the emissions from all of the production aspects.

There are other reasons for supporting organic farming over conventional farming beyond carbon emissions. The use of inorganic fertilizers contributes to run-off and can severely impact water quality through eutrophication and increased nitrate levels (Matson et al. 1997; Aneja et al. 2008). Soil conditions, such as level of organic content, are much improved with organic management (Matson et al. 1997; Drinkwater et al. 1995). There have also been health implications developing from the use of pesticides on agriculture products (Matson et al. 1997). Organic food does not contain these artificial compounds. Thus, a full analysis of all these externalities should be considered in the future policy of Canadian agriculture along with carbon emissions.

4.2 Opportunities for Emissions Reductions

There are fewer opportunities for emissions reductions than thought at the start of this research, as the farm has been making advances towards a low carbon footprint and is already making significant savings. In particular, the conservation-style tillage used allows for more carbon to remain sequestered in the soil (Lal 2004b). The use of biomass, again, is forward thinking over fuels like propane and fuel oil. Ensuring that biomass is used sustainably may be the best way to generate emission reductions on farms. Concerns with the accounting procedure for biomass have been discussed. Through clarification of these concerns, individuals may see their biomass emissions change due to reforms in calculations.

Opportunities for further emissions reductions may occur through an increase in renewable energy use. NS Power plans to increase the proportion of renewable energy that is produced (Dept. of Energy 2010). This means that the electricity emission factor will decrease regardless of action on behalf of the farmer. With an ultimate goal of 40% renewable energy, these reductions could be beneficial and significant for farmers if emissions factors dropped accordingly. There is also the possibility for renewable energy production on the farm directly, which would decrease the amount sourced from NS Power. Lastly, as an alternative to biomass heating, a solar hot water heat exchanger could be a renewable way of heating greenhouses. However, this would require a significant capital investment.

4.3 Significance

Carbon emissions are increasingly important as global warming becomes an increasing concern (IPCC 2007). Agriculture is not likely going to be reduced, the same way, reducing transportation or energy use. Food production needs to increase to meet the population demand, and thus, being able to determine more carbon efficient means of production is important. Quantifying these emissions can allow for better decisions to be made with regards to agriculture policy.

Quantifying the impact of organic agriculture on carbon emissions is important in light of the growing organic sector. As more farms become certified as organic, it is important to understand the major components of production contributing to carbon emissions. Thus, targeted reductions can spread across the industry, working towards the proposed mitigation potential of agriculture (Smith et al. 2008). Reduction of emissions, guided by carbon accounting documents, can lessen the overall emissions contributing to global warming and may provide more scientific support for promoting organic agriculture. Specifically in Nova Scotia, the organic community is small, numbering around 50 farms. Any information regarding alternative methods and new practices can disseminate widely through the region. Carbon accounting on more organic farms across Canada would allow for better averages, clearer trends, and comparisons of production in different regions.

There is also a future policy implication to consider. Certain industries (eg. natural gas companies) are required to report emissions to the Canadian government. While this is not the case for agriculture, it is a possibility in the future. This study clarified one methodological approach that would allow Canadian organic farms to calculate their emissions. This will providing increased discussion about what components need to be included, and what approach is the best way to account for the emissions.

Further research is needed to compare organic production in Nova Scotia to a comparable sized conventional farm. This will hopefully provide clarification on Canadian agriculture if emissions per unit crop are indeed less for conventional farming. Future research into specific Canadian emission factors could allow from more accurate reporting and quantifying, specifically with emissions from shipping. This study of one organic farm in Nova Scotia is part of a larger movement to understand the sources and ultimately, the potential for reductions of anthropogenic GHG emissions.

5.0 Conclusions

The key emissions were biomass, electricity, fuel, and applied fertilizers, which are all direct emissions. The indirect emissions composed around 5%, with the production of machinery as the largest component. Biomass was indeed included in the footprint, and was not carbon neutral. The studied farm showed that there were savings from current organic fertilizer, pesticide and tillage use compared to conventional methods. There are opportunities to decrease emissions further through the use of renewable energy, and a decrease in the electricity emissions factor for Nova Scotia.

Additional research is needed to compare conventional farms to organic farms in Nova Scotia context to determine the effect of yields on emissions and further contribute to the debate of organic or conventional farming, in terms of emissions. This accounting methodology can be utilized and applied to other farms, and larger regions. This will allow for more trends in GHG emissions from organic agriculture to be determined across Nova Scotia and ultimately, across Canada and the globe.

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Appendix A: Data Tables

Table A: Summary of Emission Calculations

Component	**Emissions (tonnes CO_2e)**
Fuel	6.3
Electricity	13.0
Applied Fertilizer	4.9
Tillage	0.07
Biomass	30.9
Transportation of Seeds	0.10
Transportation of Fertilizer	0.51
Production of Greenhouses	0.52
Production of Machinery	1.6
Savings	
Biomass Alternative 1 - Propane	20.4
Biomass Alternative 2 - Light Fuel Oil	25.2
Biomass Alternative 3 - Heavy Fuel Oil	25
Fertilizer	6.7
Pesticides	0.02
Tillage	0.14

Direct Emissions

Table A Calculations for Fuel

FUEL	**1999 Chevy***		**Chain Saw**		**Woodsplitter**		**Rototiller**		**Lawn Mower**		**Tractor**	
Fuel	Gasoline		Gasoline		Gasoline		Gasoline		Gasoline		Diesel	
Amount	2096.457	L	73.49	L	66.246	L	32.03	L	64.07	L	272.308	L
Fuel Factor[1]	2311.89	g CO_2/L	2311.89	g CO_2/L	2311.89	g CO_2/L	2311.89	g CO_2/L	2311.89	g CO_2/L	2689.63	g CO_2/L
Tonnes CO_2e	4.85	tonnes CO_2e	0.17	tonnes CO_2e	0.15	tonnes CO_2e	0.07	tonnes CO_2e	0.15	tonnes CO_2e	0.73	tonnes CO_2e
CH_4 Factor[1]	0.43	g CH4 /L	0.50	g CO2e / 3.785 L	0.50	g CO2e / 3.785 L	0.50	g CO2e / 3.785 L	0.50	g CO2e / 3.785 L	1.44	
GWP	25		25		25		25		25		25	
CO_2e	0.02254	tonnes CO_2e	0.00024	tonnes CO_2e	0.00022	tonnes CO_2e	0.00011	tonnes CO_2e	0.00021	tonnes CO_2e	0.00259	tonnes CO_2e
N_2O Factor[1]	0.20	g N2O /L	0.22	g CO2e / 3.785 L	0.22	g CO2e / 3.785 L	0.22	g CO2e / 3.785 L	0.22	g CO2e / 3.785 L	0.26	
GWP	298		298		298		298		298		298	
CO_2e	0.12495	tonnes CO_2e	0.00127	tonnes CO_2e	0.00115	tonnes CO_2e	0.00055	tonnes CO_2e	0.00111	tonnes CO_2e	0.00557	tonnes CO_2e
Total CO_2e	6.28	tonnes CO_2e										

* Values for the Chevy came from Table 13.2 TCR update. For both methane and nitrous oxide production, the Chevy was assumed to be a catalytic, light duty, gasoline truck (TCR Update Table 13.3).

[1] Values for Fuel factors, except for the Chevy, were from Table 13.2 TCR Update document. It was assumed that one Am gallon = 3.785L. Values for methane were from Table 13.7 TCR Update, assuming agriculture equipment category. The nitrous oxide values were from Table 13.7 TCR Update Document.

Table B Calculations for Electricity

ELECTRICITY		
Consumption	15687	kWh

Emission Factor	828.39	g CO_2e /kWh
Emissions	13.0	tonnes CO_2e

Emission factor was from: http://www.nspower.ca/en/home/environment/emissions/archived/totals.aspx

Table C Calculations for applied fertilizer.

Application

	Horse Manure		**Potting Soil**		**Seaweed**		**Fish Fertilizer**	
Mass	89000	kg	6000	kg	1000	kg	300	L
N content	0.0048	(Stout 1990)	0.30%	from Jolly Farmer Company	2%	Seaweed and Plant Growth	1%	Packaging
CE (Hillier et al. 2009)	2.84		2.84		2.84		2.84	
Factor	10.413	CO_2e	10.413	CO_2e	10.413	CO_2e	10.413	CO_2e
	4448.576	kg CO_2e	187.44	kg CO_2e	208.27	kg CO_2e	31.24	kg CO_2e
	4.448576	Tonnes CO_2e	0.18744	Tonnes CO_2e	0.208266667	tonnes CO_2e	0.03124	tonnes CO_2e

Energy		
N content	468.2	kg of N
Energy	0.0075	kg CE/kg N
	0.0275	kg CO_2e / kg N
Emissions	0.0128755	tonnes CO_2e

Table D Calculations for tillage.

TILLAGE		
Conservation		
Area	1.2	ha
Spading	8	kg CE/ha
	29.3	kg CO_2e/ha
Less Intensive	70	%
	1	trip
	0.02464	tonnes CO_2e
More Intensive	30	%
	3	trips
	0.03168	tonnes CO_2e
Conventional		
Area	0.25	ha
Emission Factor	15	kg CE/ha
	55	kg CO_2e/ha
CO2	0.01375	tonnes CO_2e
Total	0.07007	tonnes CO_2e

Table E Calculations for biomass.

BIOMASS	**Red Maple**		**White Birch**		**Yellow Birch**		**Miscellaneous**	
% of 17 cords	80%		10%		5%		5%	
Amount	13.6	cords	1.7	cords	0.85	cords	0.85	cords
MMBTU/cord	19.1		18.2		21.3		15.75	
Emission Factor	93.87	kg CO_2/MMBTU	93.87	kg CO_2/MMBTU	93.87	kg CO_2/MMBTU	93.87	kg CO_2/MMBTU
Emissions	24.38	tonnes CO_2	2.90	tonnes CO_2	1.70	tonnes CO_2	1.26	tonnes CO_2
CH_4 Factor	9.30	g/MMBTU	9.30	g/MMBTU	9.30	g/MMBTU	9.30	g/MMBTU
GWP	25		25		25		25	
CO_2e	0.06	tonnes CO_2e	0.01	tonnes CO_2e	0.00	tonnes CO_2e	0.00	tonnes CO_2e
N_2O Factor	5.9	g/MMBTU	5.9	g/MMBTU	5.9	g/MMBTU	5.9	g/MMBTU
GWP	298		298		298		298	
Total CO_2e	0.46	tonnes CO_2e	0.05	tonnes CO_2e	0.03	tonnes CO_2e	0.02	tonnes CO_2e

Indirect Emissions

Table F Calculations for transportation of seeds.

SEEDS										
Location	Winslow, Maine	Wolcott, Vermont	Parkside, SK, Canada	Delta, BC	Williams, Oregon	Dundas, ON	Penobsquis, NB	Waterville, Maine	York, PEI	Sandwich, Mass
Weight (kg)	31.65	5	108.3	23.5	1.4	20.5	45.9	4.5	5.5	0.5
miles	585	771			3671			584		820
Distance (km)	941	1241	4684	5963	5908	1969	442	940	447	1320
Factor g/tonne-km	96	96	96	96	96	96	96	96	96	96
Emissions tonnes CO_2e	0.0029	0.0006	0.0487	0.0135	0.0008	0.0039	0.0019	0.0004	0.0002	0.0001
CH_4	25	25	25	25	25	25	25	25	25	25
Factor (g/km)	0.00317	0.00317	0.00317	0.00317	0.00317	0.00317	0.00317	0.00317	0.00317	0.00317
Emissions tonnes CO_2e	7.46112E-05	9.83337E-05	0.00037120	0.00047257	0.00046820	0.00015604	3.50285E-05	7.44837E-05	3.542E-05	0.0001046
N_2O	298	298	298	298	298	298	298	298	298	298
Factor (g/km)	0.00298	0.00298	0.00298	0.00298	0.00298	0.00298	0.00298	0.00298	0.00298	0.00298
Emissions tonnes CO_2e	0.00083606	0.001101884	0.00415957	0.00529538	0.00524645	0.00174855	0.000392514	0.00083463	0.000397	0.0011719

Nitrous Oxides and Methane factors are from TCR Update Table 13.5

Table G Calculations for the transportation of fertilizers.

FERTILIZER	**TRANSPORTATION**							
	Horse Manure		**Potting Soil**		**Seaweed**		**Fish Fertilizer**	
Distance (km)	11		632	Northampton NB	97	Digby, NS	518	Souris, PEI
Type	7 loads of a 10 wheel dump truck		motor freight		pickup truck		motor freight	
Weight [1]	12.7	Tonnes/ load	6	tonnes	1	tonne	0.3	20 L buckets
	89	tonnes total						
Factor	96	g/tonne-km	96	g/tonne-km	96	g/tonne-km	96	g/tonne-km
Emissions	0.12192	tonne CO2	0.364032	tonne CO2	0.009312	tonne CO2	0.0149184	tonne CO2
CH4	0.0051	g/mi						
	0.00317	g/km	0.00317	g/km	0.00317	g/km	0.00317	g/km
Emissions	6.10031E-06	tonnes CO_2e	0.000050086	tonnes CO_2e	7.6873E-06	tonnes CO_2e	4.10515E-05	tonnes CO_2e
N2O	0.0048	g/mi						
	0.00298	g/km	0.00298	g/km	0.00298	g/km	0.00298	g/km
Emissions	6.84383E-05	tonnes CO_2e	0.000561241	tonnes CO_2e	8.6140E-05	tonnes CO_2e	0.000460005	tonnes CO_2e

1 Average weight for dumptruck taken from http://midcoasttransportation.com/fleet.htm.

Methane and Nitrous Oxides emission rates from From TCR, 2012 Update Document. Table 13.5.

Table H Calculations for the production of greenhouses.

GREENHOUSES	Galvanized Steel				Aluminum			
	20 by 60		**30 by 96**		**20 by 60**		**30 by 96**	
	1600	pounds	3500	pounds	60	pounds	80	pounds
Weight (kg)	725.75	kg	1587.57	kg	27.21	kg	36.28	kg
Quantity	5		1		5		1	
CO_2e production/use	6526	pounds CO_2e/ 2220lbs	6526	pounds CO_2e/ 2220lbs				
in kg CO_2e	2960	kg CO_2e/1007 kg	2960	kg CO_2e/1007 kg	1.5	kg CO_2/ kg	1.5	kg CO_{2e}/ kg
Emissions	2.9	kg CO_2e/ kg	2.9	kg CO_2e/ kg	0.20	tonnes CO_2	0.05	tonnes CO_2
	10.67	tonnes CO_2e	4.67	tonnes CO_2e				
Amortized over 30 years	0.36	tonnes CO_2e	0.16	tonnes CO_2e	0.01	tonnes CO_2e	0.00	tonnes CO_2e

Table I Calculations for the production of machinery.

MACHINERY	
Tractor	
2487	kg
1	
83.7	MJ/kg
1	kWh = 3.6 MJ
23.25	kWh
828.39	g CO_2e / kWh
47.9	tonnes CO2
1.6	tonnes CO2e / year

Amortized over 30 year lifespan. Tractor weight from http://www.tractordata.com/farm-tractors/000/7/6/763-massey-ferguson-254.html.

Savings

Table J Fuel Comparisons to biomass.

Alternatives						
322.1925	MMBTU		339.9130875	GJ		
	Propane		**Light Fuel Oil**		**Heavy Fuel Oil**	
Amount of Fuel	25.31	GJ/KL	38.8	GJ/KL	42.5	GJ/KL
	13.4	KL	8.8	KL	8.0	KL
	13430.0	L	8760.6	L	7998.0	L
Factor for Combustion	1518	g CO_2/L	2873	g CO_2/L	3127	g CO_2/L
Emissions	20.4	tonnes CO_2	25.2	tonnes CO_2	25.0	tonnes CO_2

Factors were from TCR Table 12.3 Update Document. 1MMBTU = 1.055 GJ

Table K Sensitivity analysis biomass.

SENSITIVITY	**ANALYSIS**		
17	cords	17	cords
2920	pounds/cord	2920	pounds/cord
1324.5	kg/cord	1324.5	kg/cord
500	g CO_2/kg	750	g CO_2/kg
11.3	tonnes CO_2	16.9	tonnes CO_2

Table L Conventional methods for fertilizer (compared to Table C)

Total N	468.2	kg	Compensated by inorganic N fertilizers
	2.58	kg CE/kg N	Hillier et al. 2009
	9.46	kg CO_2e/kg N	
	4.429	tonnes CO_2e	
Production	468.2	kg	
	1.3	kg CE/kg N	
	4.767	kg CO_2e/kg N	
	2.232	tonnes CO_2e	

Table M Conventional methods for pesticides

PESTICIDES	Admire	Maraseni et al.	Treflan		
0.2	l/ha		1.2	L/ha	.480 kg/ L
0.048	kg/ha	.240 kg AI/L	0.576	kg/ha	1.45 ha
0.0696	kg AI	1.45 ha	0.8352	kg AI	
18.7	kg CO_2e / kg AI		23.1	kg CO_2e / kg AI	
0.001	tonnes		0.019	tonnes	

Table N Conventional methods for tillage (compared to Table D)

Conventional		
Area	1.2	ha
Plow	15	kg CE/ha
	55	kg CO_2e/ha
Emissions	0.07	
Light Disking	8	kg/ha
	29.3	kg CO_2e/ha
Frequency	2	
Emissions	0.07	

Table O Conventional methods for transportation

TRANSPORTATION				
Toronto, ON				
Distance	1743	km	200	km
Mass	0.100	tonne	0.100	tonne
Emission	96	g CO2e/tonne-km	96	g CO2e/tonne-km
	0.017	tonnes CO_2e	0.0019	tonnes CO_2e