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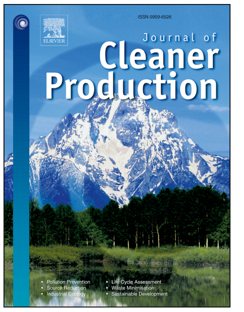

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Sarah Keyes, Dr. Peter Tyedmers, Dr. Karen Beazley

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Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment.

Sarah Keyes *

School for Resource and Environmental Studies, Faculty of Management, Dalhousie University, 6100 University Avenue, Suite 5010, Kenneth C. Rowe Management Building, Halifax NS, Canada, B3H 3J5. Email address: sarah.keyes@dal.ca

Dr. Peter Tyedmers

School for Resource and Environmental Studies, Faculty of Management, Dalhousie University, 6100 University Avenue, Suite 5010, Kenneth C. Rowe Management Building, Halifax NS, Canada, B3H 3J5. Email address: Peter.Tyedmers@dal.ca

Dr. Karen Beazley

School for Resource and Environmental Studies, Faculty of Management, Dalhousie University, 6100 University Avenue, Suite 5010, Kenneth C. Rowe Management Building, Halifax NS, Canada, B3H 3J5. Email address: Karen.beazley@dal.ca

* Corresponding author. [1] Tel: 011 1 613 929 6145. sarah.keyes@dal.ca (S. Keyes).

[1] Present address: 119 James St. Apt. 2 Kingston, Ontario. K7K 1Z5

Abstract

Life cycle assessment (LCA) was used to characterize the environmental performance and potential improvement opportunities related to conventional and organic apple systems in Nova Scotia, Canada. The goal was to quantify and evaluate resources and energy required for production, storage, and transportation, determining how each supply chain sub-system contributes to relevant global scale environmental burdens. Importantly, scenario models were constructed to explore performance improvement opportunities related to key supply chain inputs. Results indicate that up to point of harvest, the combustion of diesel fuel, production and associated field-level emissions of fertilizers (i.e. synthetic and manure), and inputs to pest and disease management were major contributors to environmental impacts on both conventional and organic orchards. Extending system boundaries to cradle-to-retail locations (both local and distal), revealed, somewhat surprisingly, that electricity needed for long-term storage resulted in substantial burdens, highlighting the problems of coal-based electricity generation in Nova Scotia. Consuming locally produced apples when in season was found to be environmentally preferable to those requiring year round storage, while transport by freight ship is more favourable than long distance transport truck delivery.

Keywords: Life cycle assessment, Apple supply chains, Environmental impacts, Conventional, Organic, Agriculture

Total word count: 7,706 [5,594 (Text file) + 2,079 (Tables) + 33 (Figure captions)]

1. Introduction

Global food systems are contingent on resource and energy inputs, as they are required for the production and provision of food. This consumption is associated with environmental alterations including changes to habitat and biodiversity loss (Butler et al., 2007), emissions to air, water, and soil (Foster et al., 2006), and potentially unsustainable depletion of materials and non-renewable energy (Matson et al., 1997; Carlsson-Kanyama et al., 2003). With the productive capacity of current and future agricultural systems in mind, some farmers have begun to employ management techniques that attempt to protect the environment and improve biological and natural processes. Apple producers in Nova Scotia, Canada are engaging in these practices, where upwards of 95 percent of growers employ some measure of integrated pest management (IPM), and organic production is beginning to emerge (Canadian Horticultural Council, 2009).

Understanding how, and to what extent, conventional improvements such as IPM and organic production practices contribute to relative environmental burdens is a prerequisite to moving towards more sustainable food systems (van der Werf & Petit, 2002; Roy et al., 2009). Although there is a growing body of literature with this focus (e.g., Cederberg & Mattsson, 2000; Haas et al., 2001; Pimentel et al., 2005; Pelletier et al., 2008; De Backer et al., 2009; Mouron et al., 2012; Venkat et al., 2012), further research is required at local scales to address unique challenges and opportunities. Life cycle assessment (LCA) was used here to evaluate the environmental performance of apple systems in Nova Scotia, Canada, with the intention of pinpointing areas where greater resource and energy efficiencies could be achieved, an essential step in minimizing environmental impacts of agriculture.

LCA was employed to quantify the material and energy inputs of apple production in Nova Scotia, measuring its contribution to several global-scale resource depletion and environmental concerns. LCA is well suited to inform how orchard activities and beyond are affecting both resource depletion and emission-based impact categories, as results can pinpoint sub-systems in the life cycle where the greatest improvements in environmental performance can be achieved. The four-step analytical LCA framework provided by ISO-standardized guidelines (ISO, 2006a,b) was followed in the present study.

LCA has been used to study apple production systems in the past (e.g., Stadig, 1997; Blanke & Burdick, 2005; Mouron et al., 2006a,b; Mila i Canals et al., 2006 & 2007; Sim et al., 2007; Saunders & Barber, 2008; Cerutti et al., 2013), but to date no research of this kind has been conducted in an Atlantic Canadian context despite the prominence of the sector regionally. Thus the impetus for this research was to identify opportunities to improve the environmental performance of regional conventional and emerging organic apple supply chains to better position the sectors in the face of inevitable increased environmental scrutiny. More broadly, it is hoped that substantive and methodological insights from the work will benefit the broader food system and LCA practice communities.

2. Materials and Methods

Apple production is a significant industry in Canada, valued at $148.5 million in 2010 (Agriculture and Agri-Food Canada, 2012). Nova Scotia represents approximately 10 percent of the Canadian apple industry and contributes substantially in terms of economic impact for the province. In 2010, the 33,700 tonnes of apples produced had a farm-gate value of $12.2 million and a wider economic spin-off of $61 million (Statistics Canada, 2012). Within Nova Scotia, production is located primarily in the Annapolis Valley, where over 150 farms produce apples on approximately 1850 hectares of land (Statistics Canada, 2012). Apples produced in Nova Scotia are destined for diverse markets, including local retail, processing into value-added products (e.g., juice, pies, and ciders), and export.

The central objectives of this project were to characterize the life cycle environmental performance of typical commercial apple systems and of the emerging organic apple system in Nova Scotia. Direct comparisons of the two modes of production have not been made because substantial differences exist between them, including the age of operations, scales of production, and levels of output. Comparing conventional orchards – with decades of additional experience in developing farm efficiencies and honing high yield practices – to organic production in Nova Scotia was not justifiable. Conventional and organic apple systems were thus characterized independently and results presented as such.

2.1 Data Collection

Data were collected and analyses undertaken on both cradle-to-farm-gate and cradle-to-retail-gate system boundaries for conventional and organic apple production. Noteworthy, while a cradle-to-retail-gate system scope was modeled for organic production, data on storage inputs obtained for this study reflect conventional apple storage. This scenario model was developed to understand how organic production would fair if post-production systems of storage in organic mirrored those of conventional production. The 2010 growing season was the temporal scope of analysis used in this study, while one tonne of apples produced was the functional unit of analyses employed.[2]

2.2 System Boundaries

Farm-level analyses included all major production processes, including inputs to land preparation, infrastructure, farm equipment, fuel use, soil amendments and fertilizers, and chemical and non-chemical crop inputs (Figure 1). Post orchard production sub-processes included storage inputs, and transport to various retail locations throughout Canada and abroad via transport truck, rail and freight ship **[Insert Figure 1].**

2.3 Life cycle inventory data

Contact information for 30 conventional and 8 organic producers was available through online searches, forming the list of orchardists contacted by email and phone to participate in the study. Consultation with industry informants ensured this sample was geographically representative of the Annapolis Valley, and that producers operating on a range of orchard sizes (i.e. <1 to >50 ha) were sampled. Questionnaires on 2010 season inputs were sent by email to orchardists and storage facility operators, with follow-up phone communication allowing for complete data collection. Inputs were averaged using 2010 production tonnage as the weighting factor to produce a representative model of

[2] Mass and area-based functional measures provide information relevant to determining preferable levels of production intensity (Nemecek et al., 2011). Refer to Keyes (2013) for per hectare results and analyses for both conventional and organic apple systems.

Nova Scotia apple production. Similarly, storage input data were compiled and averaged using storage volumes for the 2010 season.

Field level greenhouse gas emissions from fertilizer and manure applications were estimated following methods employed by Point and colleagues (2012) and Pelletier (2006), both of which based calculations on Brentrup et al. (2000), the Intergovernmental Panel on Climate Change (IPCC, 2006), and Dalgaard et al. (2006) (see Table 1 and Keyes, 2013, for details). Although consensus on emission potentials from fertilizers and manures has not been reached, and external variables such as soil type, climate, rate of application and nutrient uptake can affect their accurate calculation (Eichner, 1990; Pelletier, 2006), comparative emission potentials were nevertheless calculated for nitrogen, phosphorus, and carbon dioxide using best available information in the literature, serving to represent emission potentials for this study. Background system and upstream life cycle processes were compiled primarily from the EcoInvent 2.2 database, with additional peer-reviewed LCA databases (e.g., US LCI 1.6, ELCD 2.0) used when necessary (Keyes, 2013). Electricity production mixes were developed to reflect the temporal and location-specific realities of the electricity grid analyzed.

Grade specific (i.e., direct consumption; processing) allocation of apples was not conducted in this analysis, as has been undertaken in some past apple LCA research (e.g., Mila i Canals et al., 2006; Sim et al., 2007). Although co-production of grade specific apples occurs, both those intended for direct consumption and those for processing are sent to storage facilities before reaching their final destinations, thereby using inputs involved in the storage process. Separate partitioning of apple grades was also unnecessary due to the fact that an integrated average of apples stored throughout the year was used to determine the amount of materials used per tonne of apples, following the project's objectives to understand the environmental impacts of typical commercial (conventional and organic) apple production in Nova Scotia, rather than those with superior or inferior economic value. Moreover, grade specific data were unavailable for this project.

Table 2 displays characteristics of orchard data obtained from ten conventional and three organic growers that completed surveys for the 2010 season, representing a 33 and 37.5 percent response rate, respectively. These data underpinned the weighted averages used in the calculation of sub-system contributions to impact categories. In total, data received represents ~15 percent of the total conventional apple growing area in Nova Scotia. Statistics on total organic orchard production in Nova Scotia are unavailable; however, data were obtained from three of the eight known producers in the province. Tables 3 and 4 display detailed life cycle inventory results for conventional and organic orchard data collected, respectively, with results displayed per tonne of apples produced.

2.4 Life cycle impact assessment

Model construction was facilitated by the use of a LCA software program, SimaPro, version 7.3.3, allowing for inventory data to be quantified in relation to relative impact categories, employing characterization factors from established impact assessment characterization models (for more detail see Keyes, 2013). Upon recommendation from an LCA consultant, and consideration of recently published agricultural LCAs (e.g., Rugani et al., 2012) the impact assessment methods package 'Recipe H' (Goedkoop et al., 2010) was used to quantify global warming potential (GWP), photochemical oxidant formation potential (POFP), terrestrial acidification potential (AP), freshwater and marine eutrophication potential (FEP & MEP), metal depletion potential (MDP), and fossil depletion potential (FDP). Human cancer and non-cancer toxicity potential (HCTP, HNCTP), and aquatic eco-toxicity potential (ETP) were quantified using the UseTox methodology, recently developed through the UNEP-SETAC Life Cycle Initiative (Goedkoop et al., 2010), and cumulative energy demand (CED) was calculated independently as a single issue impact.

2.5 Scenario modeling and sensitivity analyses

Focusing on transportation and electricity generation, several scenarios were modeled to explore the effects of future and hypothetical changes to the apple supply chain in order to understand how they impact life cycle burdens. Scenario models were designed by considering possible changes to the baseline model that may have an effect on environmental performance, with models constructed around supply chain sub-systems that made a substantial contribution to the relative contribution of the life cycle. All scenario models were constructed using data from conventional orchard production and analyzed using impact categories identified in section 2.4.

Five transportation scenarios, identified using insight from Agriculture and Agri-Food Canada (2012) and questionnaire responses from orchard and storage operations (Table 5), were conducted to understand how distance and mode of transport affect the life cycle burden of apples. Wide-spread interest in the concept of ‘food miles’ and the impact of export-oriented food systems, coupled with debates over local production (e.g., LaTrobe & Acott, 2000; Schlich & Fleissner, 2005; Smith et al., 2005; Edwards-Jones et al., 2008; Weber & Matthews, 2008; Coley et al., 2009; Duram & Oberholtzer, 2010; Mundler & Rumpus, 2012) prompted this investigation. Post-production stages such as storage and transport have been the focus of apple LCAs in the past (e.g., Blanke & Burdick, 2005; Sim et al., 2007; Mila i Canals et al., 2007), therefore it was also pertinent to understand how apples from Nova Scotia would fare in these discussions and what impact transportation makes to overall life cycle burdens. All scenarios were modeled from cradle-to-farm-gate, with transport originating in Kentville, the approximate center of Nova Scotia apple production. Return trips were not included.

Given that Nova Scotia's energy generation is principally dependent on imported coal, accounting for 57% of the primary energy inputs in 2011 (Nova Scotia Power Inc., 2012), it was important to understand the role this plays in the life cycle of apples. Three improvement possibility scenarios were therefore modeled to explore potential environmental benefits that could arise from modifications to this key supply chain input (Table 6). Scenario E1 works from the projection that 40 percent of electricity in the province will be generated by renewable sources by 2020 (Nova Scotia Department of Energy, 2010). Coal continues to dominate in this scenario, providing 34% of electricity generated, while wind and hydropower increase to 19 and 21% respectively. Scenario E2 builds on this model, replacing coal entirely with natural gas, which accounts for 54% of the electricity generated, while wind and hydropower each represent 19 and 21% respectively, following Nova Scotia's 2020 mandate. Finally, Scenario F was modeled to understand how life cycle impacts would vary if apple storage were to be undertaken in a province almost entirely reliant on renewable sources of electricity. This scenario is identical to scenario C in which conventionally produced Nova Scotia apples are shipped to Houston, TX, with the exception that upon harvesting, apples are trucked to Montreal, Quebec for storage. Electricity inputs were changed to mirror the reality in Quebec, where 97% of electricity is generated by hydropower.

Sensitivity analyses were conducted to assess the effect of variability and uncertainty in data and assumptions on modeled outputs in the pursuit of testing the robustness of conclusions. Six sensitivity tests were conducted, where changes to inputs of fuel use, chemical and non-chemical pest and disease management inputs, and fertilizers and manure used on conventional and organic orchards were investigated. Tests were conducted by modeling a 10% increase/decrease on each of these parameters. A 10% value was chosen due to the probability that input variations would be within this range, and also so sensitivity test results could be compared to higher input percentage changes (i.e. 20 – 50, etc.) without difficulty.

3. Life cycle impact assessment results

Tables 7 and 8 present a detailed account of life cycle contributions from both cradle-to-farm-gate and cradle-to-Halifax-retail-gate for conventional and organic systems, while Table 9 details field level emissions generated by orchard activities.
In the conventional cradle-to-farm-gate model, impacts were driven largely by fuel use, and fertilizer and chemical inputs to production, while farm ancillaries (e.g. infrastructure) made a relatively small contribution overall (Table 7). Fuel use contributed most significantly to GWP (41%), POFP (83%), FDP (46%), and CED (36%), and led to significant impacts to AP (20%), caused primarily by the combustion of

diesel fuel. Nitrogenous emissions resulting from the application of fertilizers on orchards led to the majority of burdens for AP (67%) and MEP (78%). Specifically, NH_3 emissions to air contribute most substantially to AP, while MEP is driven by NO_3 leaching to water, as well as volatilization of NO and NH_3 to air. Further, the provision of P-fertilizers, along with resulting P_2O_5 emissions to water cause substantial impacts to FEP (54%), while production of N-fertilizers and associated N_2O emissions also contributed to GWP (18%). Chemical inputs to orchard production dominated metal and toxicological impact categories. Indeed, MDP (56%), HTCP (95%), HTNCP (94%), and ETP (100%) were underpinned by electricity and materials required for the production and provision of fungicides and growth regulators, as well as emissions to air, water, and soil from their application. Chemical inputs were also responsible to burdens to GWP (21%), FEP (39%) FDP (33%), and CED (32%), driven by energetic inputs of herbicides, fungicides and growth regulators. Other non-trivial on-orchard processes include inputs to machinery and infrastructure, which caused 21% and 20% of impacts to MDP, respectively, driven primarily by the manufacturing of steel.

When a cradle-to-Halifax retail gate is modeled for conventional production, the most significant impacts resulted from electricity for storage and on-orchard production activities (Table 7). Electricity for storage drove impacts for GWP (63%), FEP (52%), FDP (57%), and CED (54%), with the combustion of coal as the underpinning cause. Meanwhile, orchard production inputs accounted for the main burdens to POFP (46%), AP (54%), MEP (84%), MDP (67%), and the toxicity potentials of HTCP (84%), HTNCP (96%), and ETP (100%), driven by fuel, fertilizers, and chemical inputs.

For organic production up to farm-gate, relative contributions to life cycle impacts originated from a diverse range of sub-systems (Table 8) Combustion of diesel fuel was a major source of burdens, dominating GWP (37%), POFP (80%), FDP (38%), HTCP (57%), and making substantial contributions to CED (23%), and ETP (31%). Manure fertilizers were noteworthy in terms of life cycle impacts, where nitrogenous emissions resulting from the application of manure on orchards drove AP (74%) (i.e. NH_3 to air) and MEP (89%) (i.e. NO_3 to water; NO and NH_3 to air). Further, manure-based phosphorus emissions contributed significantly to FEP (67%) due to P_2O_5 emissions to water, and caused substantial burdens to GWP (24%) by the release of N_20 to air. Non-chemical crop management was the main source of burdens for HTNCP (56%), and a secondary driver of MDP (41%), while contributing substantially to FEP (15%), FDP (32%), CED (20%), and ETP (25%). These burdens arose largely from the production and use of copper and sulfur used for disease and pest treatments on organic orchards. Inputs to land preparation drove CED (30%), largely as a result of electricity used in hay production. Finally, farm machinery was the main source of MDP (49%), and caused notable burdens for HTCP (20%), HTNCP (20%), and ETP (34%), due centrally to the electricity and toxins associated with the manufacturing of steel.

Similar to the conventional production supply chain, most burdens of the organic production to Halifax-retail supply chain originate from electricity and key on-orchard production activities (Table 8). Specifically, coal driven electricity generation for storage was responsible for the majority of impacts to GWP (61%), FEP (54%), FDP (54%), and CED (46%). In contrast, on orchard production practices were the primary cause of POFP (49%), AP (71%), MEP (89%), MDP (72%), and HTNCP (83%). Interestingly, materials associated with storage and packing led to the largest contributions for ETP (94%), driven mainly by potato starch needed for the manufacture of corrugated cardboard boxes. Meanwhile, shipment of apples via transport truck from Kentville to Halifax resulted in the largest contributions to HTCP (34.9%).

3.2 Scenario modeling and sensitivity test results

Transportation scenarios were constructed to understand how mode and distance of transport affect life cycle burdens of apples. Not surprisingly, the further distance apples are shipped within North America via transport truck, the greater the environmental burdens become, increasing 40 percent or more in impacts to GWP, POFP, MDP, FDP, CED, and HTCP when the baseline Halifax scenario (A) was compared to transport to Montreal (B1) (Table 10). Meanwhile, when the method of transport was changed to freight rail, results indicate that the relative contribution of transport decreased substantially compared to the impact associated with transport truck use (scenarios B1 to B2 in Table 10). Similarly, comparing impacts of apples transported to Houston and London, England (scenarios C and D, respectively), two retail destinations of similar distances (Table 5), shipment by freight ship to London resulted in much lower emissions (11-70% across almost all categories studied) than shipment to Houston via transport truck**. [Insert Figure 2]**

Modeled improvement possibility scenarios revealed that moving away from coal-based electricity generation would markedly reduce the environmental impacts of Nova Scotian apple supply chains, particularly, when renewable electricity generation options were considered. Under scenario E1, in which renewable energy plays a greater role as mandated by current government policy (Table 2), impacts to GWP, POFP, AP, FEP, FDP, and CED were between 10 and 21 percent below the baseline scenario A (Table 10). Further, when natural gas substitutes entirely for coal (scenario E2), life cycle impacts were reduced between 14 and 51 percent across the same impact categories (Table 10). **[Insert Figure 3]**

Finally, sensitivity tests conducted did not significantly change burdens to most impact categories under investigation when compared to the cradle-to-farm-gate baseline models (see Keyes, 2013). Tests on fuel inputs on conventional and organic orchards were negligible save for impacts of POFP which saw ~8% change in burdens. Crop management tests for conventional orchards were negligible except for toxicity related categories (with changes between 7 and 9%), an unsurprising outcome given their relative role in toxicological impact categories. On organic orchards, crop management sensitivity tests resulted in changes of 3% or less across all fields. Fertilizer tests were not noteworthy except for results to acidification and euthrophication impact categories, with changes between 6 and 8% on both conventional and organic orchards, corresponding to the relative role these inputs play in burdens to these impact categories.

4. Discussion

Previous research has investigated environmental impacts of apple production using both LCA and non-formalized life cycle methodologies (Reganold et al., 2001; Jones, 2002; Mila i Canals et al., 2006; Mouron et al., 2006a,b; Cerutti et al., 2013). Despite differences in methodological decisions (e.g., system boundaries) and ways of reporting results, qualitative comparisons can be drawn in the context of Nova Scotia apple production. In terms of on-orchard impacts, for example, energy and fuel consumption has been identified as a hotspot in past cradle-to-farm gate apple LCAs (Mila i Canals et al., 2006; Mouron et al., 2006b), as well as in non-standardized cradle-to-retail gate life cycle studies (Saunders & Barber, 2008), corresponding with findings in Nova Scotia. Previous studies have also reported that pesticide use cause burdens to energy- and toxicity-related impact categories (Mila i Canals et al., 2006; Mouron et al., 2006b), further supporting results here. Additionally, past studies have shown that the provision of N and P-fertilizers and their associated emissions to air and water can drive eutrophication potentials (Mouron et al., 2006b) and can play a noteworthy role in GWP (Mila i Canals et al., 2006), corresponding with present results. Interestingly, emissions from N-fertilizers played a more substantial role to acidification in Nova Scotia than has been the case previously (Mila i Canals et al., 2006), where fertilizers came second to energy related acidifying emissions.

Moving beyond apple cultivation to include post-harvest activities such as storage and transportation, various life cycle studies have been conducted to understand the environmental impacts of producing and consuming domestic versus imported apples (Stadig, 1997; Jones, 2002; Blanke & Burdick, 2005; Sim et al., 2007; Mila i Canals et al., 2007; Saunders & Barber, 2008). Contributing to debates over 'food miles' and local food production, many of these geographically focused studies have found that procurement of locally produced apples can be environmentally superior to imports, with transportation cited as the primary cause of impacts (Stadig, 1997; Jones, 2002; Blanke & Burdick, 2005; Sim et al., 2007). Indeed, Stadig (1997) found that consuming apples produced and cold stored in Sweden resulted in less environmental impacts than importing them from New Zealand, despite production efficiencies in the latter country. Similarly, Sim and colleagues (2007) found that apples produced and stored in the U.K. for ten months were less impactful than those imported from Italy, Chile or Brazil; while Blanke & Burdick (2005) found that apples produced in Germany and cold stored for five months resulted in lower impacts than when importing the fruit from New Zealand. Discrepancies in methodological choices made in these studies, however, have been identified, including lack of accounting for country specific variations in production, timing of consumption and length of storage (Mila i Canals et al., 2007), and the use of outdated data sets (e.g., Blanke & Burdick, 2005). Problems of methodological inconsistencies are further highlighted when results from Jones (2002) and Saunders et al. (2008) are examined. Indeed, Jones (2002) suggests that apples produced, stored, and consumed in the U.K. have a more favourable environmental profile than those shipped from New Zealand, while Saunders and Barber (2008) come to the opposite conclusion. These studies emphasize the need to employ comprehensive and consistent system boundaries when comparisons are being made (Edwards-Jones et al., 2008), as well as the usefulness in following ISO-standardized LCA guidelines.

Such methodological shortcomings are addressed by Mila i Canals and colleagues (2007) in their comparison of primary energy consumption of domestic and imported apples, where the analysis accounted for country specific energy inputs of apple provision and associated variability, as well as storage and seasonality, and transport mode and distance. Their findings indicate that impacts are highly dependent on these input variables. For example, the relative impacts of shipping apples between European countries by transport truck is similar to the impact intensity of those sent to Europe by ship from countries in the Southern hemisphere (especially during the northern spring and summer), highlighting efficiencies in transport by freight ship. Similarly in Nova Scotia, differences in transport methods have been identified as important to environmental impacts (Table 10). Consequently, recommendations that emerge from Mila i Canals et al. (2007) suggest that on an energetic basis it may be environmentally preferable to eat a combination of domestic and imported apples, rather than advocating for procurement of locally produced apples as prior studies have (e.g., Sim et al., 2007; Blanke & Burdick, 2007). While it is beyond the scope of this research to determine whether consuming locally produced apples in Nova Scotia is more environmentally benign than imports, results produced are of value in further understanding the environmental impacts of fruit production in the province. More importantly, though, review of previous studies highlight the need to consider all supply chain inputs, and to be aware of methodological assumptions before drawing conclusions on the relative environmental benefits of local or imported apple consumption.

Several hotspots of environmental burdens arose in the cradle-to-farm-gate analyses that suggest opportunities for management actions to improve environmental outcomes. Up to the farm gate, combustion of diesel fuel was found to be a major driver of life cycle impacts on both conventional and organic orchards. Reducing diesel inputs would therefore lead to decreased burdens across all impact categories. To do so, a targeted substitution of some forms of human labour for machinery inputs may lead to impact reductions as has been suggested in previous research (Mila i Canals et al., 2006). However, the scale, specific function substitution, and trade-offs would require further detailed study (Rugani et al., 2012), which is beyond the scope of this research. In lieu of this, a well-planned organization of picking activities that optimizes use of tractors and human labour is recommended (Mouron et al., 2006b). Meanwhile, fuel efficiency could be improved by using tractors with smaller, fuel-efficient engines; ensuring that machinery is well maintained (Mouron et al., 2006b); changing oil and filters according to manufacturer's suggestions; and avoiding long periods of idling (Desir, 2006).

In order to reduce impacts caused by synthetic chemical application on orchards, producers could further employ integrated pest management (IPM) practices that integrate behavioral, biological and chemical tactics to control pests rather than relying predominantly on chemical-based targeted spraying regimes (MacHardy, 2000).[3] Education on IPM tactics, sharing of spray reduction techniques between orchardists, and the use of low-impact and less toxic pesticides is essential in these efforts (Craig, 2010). Producers could also plant disease resistant cultivars and employ new technologies such as drift reducing measures to help reduce chemical use on orchards (Mouron et al., 2012). These measures could also be taken up by organic producers to reduce copper and sulphur use, which contributed substantially to life cycle impacts of organic production. All apple producers could benefit from promoting an ecological balance and facilitating overall tree health (e.g., by use of foliar nutrients; organized orchard architecture) to help reduce susceptibility to disease (Phillips, 2005).Taking a non-allopathic approach to pest and disease management can be beneficial for both conventional and organic production systems (Keyes, 2013). Reducing the amount of pesticide treatments may not only decrease environmental burdens, it can also lead to less toxicological exposure to both humans and natural systems, which is of increasing concern to consumers in terms of

[3] While IPM tactics are used in Nova Scotia, the degree to which they are employed ranges significantly between producers, similar to other apple growing regions (Mouron et al., 2012).

personal and ecological health, as well as food safety and quality (Bourn & Prescott, 2002). Furthermore, economic incentives exist for reducing such inputs, in terms of monetary costs for their purchase and labour for their application.

The provision of nitrogen and phosphorus based fertilizers (i.e. synthetic and manure) and their related emissions to air and water were the cause of the majority of eutrophication and acidifying impacts on both conventional and organic orchards, and also led to noteworthy contributions to global warming potential. On top of reducing the overall volume of fertilizers used on orchards, additional options for decreasing impacts associated with fertilizers include planting nitrogen fixing cover crops (Pelletier et al., 2008); expansion of cultivars with high nutrient uptake capacities, as well as varieties with low nitrogen requirements (e.g. Cortland, McIntosh, Gravenstein, and Golden Delicious); ensuring a balanced and properly executed nutrient management regime (e.g., lower volumes applied at well-planned and seasonally sensitive times) (Mila i Canals et al., 2006); and choosing fertilizers and manures with less nitrogen content and those less prone to subsequent field-level emissions (Brentrup et al., 2001). Fertilizer improvement, however, must be undertaken in parallel with the maintenance of fruit quality and optimal yields, as these are all essential factors in successful apple production.

The importance of how energy is generated in Nova Scotia is revealed in the cradle-to-Halifax retail analyses for both conventional and organic production, as results show that the contribution of electricity for controlled atmosphere and cold room storage is substantial. Despite the fact that packing and storage facilities in the province operate in a highly efficient manner, the electricity needed for their operations reflects a poor environmental profile, highlighting the challenge of extending local seasons through storage when electricity generation is produced primarily using coal. The government of Nova Scotia is well aware of the problems inherent in coal-based electricity production and has designed policy changes to ameliorate the issue, which can be seen in their renewable energy targets for 2020 and beyond (see Nova Scotia Department of Energy, 2009, 2010 & 2012). Unfortunately, scenarios E1 and E2 show that even with the actualization of these targets, electricity generation will continue to be a hotspot in the life cycle of apple production, albeit on a reduced scale. In light of these findings, it is crucial that provincial energy targets currently in place are achieved and further advancements are made for environmental improvements to be realized. This can be assisted by policies and investments in renewable energy, energy efficiency and conservation, the implementation of which could both help reduce environmental burdens and lead to economic benefits in terms of cost-effective tactics for storage facility operators.

Although results allowed for the development of important improvement recommendations, limitations did occur during this research project. Temporally constraints were experienced: despite the fact that whole tree life cycles and full crop rotations are preferable in agricultural LCAs (Cowell, 1998 in Mila i Canals, 2003), production and storage data was collected solely for the 2010 season given both time and financial restrictions. As well, some spatial factors (i.e. orchard management practices and farm locations) were not specifically accounted for, since analysis was conducted using aggregated data instead of comparison on a case-by-case basis. Nemecek & Gaillard (2010) argue, however, that large samples can serve to obtain representative and reliable LCA data to account for variability amongst farms, a condition met in this research. Finally, this LCA did not conduct a full cradle-to-grave analysis. Decisions to exclude processing, consumer (e.g., transport and storage at the household level) and disposal methods were supported by boundaries of agricultural LCAs in the past (e.g., Mila i Canals et al., 2007a; Sim et al., 2007), and were not required given the project's research aims.

5. Conclusion

The vulnerabilities of global food systems and their deleterious effects on the Earth have been identified for decades, amplifying the impetus for research on ways to improve methods of production, distribution, and consumption (Ehrlich & Ehrlich, 2013). Indeed, ensuring that food systems are both resource and energy efficient is crucial in reducing the environmental impacts they produce. LCA is well positioned to aid in this process, providing a robust evaluation of environmental performance so that sound policy and praxis decisions can be made. Further, as life cycle thinking has been declared a prerequisite for any rigorous sustainability assessment (Klöpffer, 2003), the application of LCA to apple production systems in Nova Scotia is important given the value of the industry in the province by helping ensure the apple industry is in line with objectives expressed in the province's *Environmental Goals and Sustainable Prosperity Act* and greenhouse gas emission reduction targets. More broadly, results of agricultural LCAs can aid in reducing the ecological impacts of food supply chains by identifying hotspots in production and developing improvement recommendations, which could ultimately assist in establishing more productive and resilient food systems.

This LCA investigated the environmental performance of conventional and organic apple production systems in Nova Scotia in order to understand how life cycle sub-systems contribute to relevant environmental impact categories. Findings indicate that fuel use, N and P-fertilizers, and inputs for pest and disease management on both conventional and organic orchards were the drivers of burdens to impact categories under investigation. When system boundaries were extended to retail locations, attention is drawn to the electricity used for storage and the role of transportation, highlighting problems of coal-based electricity generation in Nova Scotia, as well as the efficiency of freight ship and rail when compared to trucking over long distances. Taking these hotspots into consideration, improvement recommendations were developed with the goal of reducing the life cycle environmental impacts of apple supply chains.

In line with conclusions drawn by Mila i Canals and colleagues (2006), we argue that while the scientific evidence provided by LCA studies is essential, of perhaps equal importance is the implementation of improvement recommendations, for mitigating the impacts of global food systems means that real world changes must be made. As such, effective dissemination of LCA results is paramount, producing and communicating improvement possibilities in ways that are relevant to producers, industry, and government they affect. To do so, presenting results in such ways that relate to socio-economic and political needs is crucial, contextualizing improvements so that benefits can be understood beyond the ecological realm (Mila i Canals et al., 2006).[4] This can be carried out, for example, by combining decision-support models with LCA (e.g.,

[4] Several communication attempts occurred (via email and phone) with results presented in lay and in socio-economic context, but with only 2 responses from Nova Scotian producers, we are under the impression that 2010 conditions continue to apply as no major changes in circumstances are evident to date.

Zimmermann et al., 2011). Although beyond the scope of this article, this is an avenue for future research endeavors.

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Table 1. Field level emission calculation formulas

Emission calculations from direct & indirect calculation steps [a]	Formulas
Nitrogen Emissions	a. Total N_2O–N to Air: Per tonne X = ∑ (Indirect N_2O Emissions from NO_3 + Indirect N_2O Emissions from NH_3-N +Fertilizer lost as NO_2) * (N_2O–N conversion to N_2O) b. Total NH_3–N to Air: Per tonne X = (Total NH_3-N) * (NH_3-N conversion) c. Total NO–N to Air: Per tonne X = (Fertilizer lost as NO)*(NO-N conversion) d. Total NO_3–N to Water: Per tonne X =(NO_3 Emissions) * (NO_3-N conversion)
Phosphorus Emissions	a. Total P_2O_5 –P to water: Per tonne X = (Total Remaining Phosphorus * Leaching rate of phosphorus) *(P_2O_5–P conversion to P_2O_5)
Carbon Dioxide Emissions	a. CO_2 emitted from calcite limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) applied during land preparation: Per tonne X = (2.99 * 0.12)+(4.15 * 0.13) * (44/12: CO_2–C conversion to CO_2) b. CO_2 emitted from dolomite and calcite limestone applied during 2010 nutrient management: Per tonne X = (1.2 * 0.12) * (44/12) c. CO_2 emitted from urea fertilizer applied during 2010 nutrient management: Per tonne X = (1.2 * 0.12) * (44/12)

a. Refer to Keyes (2013) for complete calculation steps.

Table 2. Combined orchard production characteristics

Orchard Data	Unit	Conventional orchards (n=10)	Organic orchards (n=3)
Combined orchard size	ha	282.86	19.02
Combined annual production	tonnes	6691.68	225.82
Yield	tonnes/ha	23.66	11.88

Table 3. Life cycle inventory for 2010 conventional Nova Scotia orchard production of 1 tonne of apples (crop yield: 23.66)[1]

Material and Energy Inputs	Unit	Per tonne	Material and Energy Inputs	Unit	Per tonne
Land Preparation [a, b]			**Pest and Disease Management** [a, d]		
Calcite limestone	kg	2.99	Captan	kg	0.71
Dolomite	kg	4.15	Mancozeb	kg	0.03
Compost	kg	8.10	Dithiocarbamate-compounds	kg	0.19
Hay	kg	3.99	Fungicides	kg	0.19
N-fertilizer	kg	0.044	Glyphosate	kg	0.37
P-fertilizer	kg	0.039	Bipyridylium-compounds	kg	0.03
K-fertilizer	kg	0.039	2,4-D	kg	0.09
Fumigant 1,3-dichloropropene	kg	0.31	Mineral Oil	kg	1.00
Glyphosate	kg	0.002	Herbicides	kg	0.06
			Insecticides	kg	0.01
Nutrient Management [a, c]			Pyretriod-compounds	kg	0.0006
N-fertilizer	kg	0.81	Growth regulators	kg	0.14
P-fertilizer	kg	0.95	Ammonium sulphate	kg	0.006
K-fertilizer	kg	1.02			
Urea, as N	kg	0.30	**Trellis System & Infrastructure** [a]		
Zinc	kg	0.005	Steel wire	kg	0.09
Zinc sulphide	kg	0.02	Steel posts	kg	0.40
Magnesium sulphate	kg	0.11	Wooden posts	kg	3.60
Calcium chloride	kg	0.64	Wood preservative	kg	0.11
Boron	kg	0.02	Polyvinylchloride	kg	0.001
Calcite limestone	kg	1.20	Wooden storage boxes	kg	2.38
Mulching	kg	0.30			
			Fuel Use [a]		
Orchard Machinery [a]					6.88
Tractor	kg	0.53	Gasoline	L	1.69
Farm implements	kg	0.26	Liquified petroleum gas	L	0.27
			Transport to Storage		
			Single unit gasoline truck	tkm	23.8

[1] Notes for Tables 3 & 4 below Table 4.

Table 4. Life cycle inventory for 2010 organic Nova Scotia orchard production of 1 tonne of apples (crop yield: 11.88)

Material and Energy Inputs	Unit	Per tonne	Material and Energy Inputs	Unit	Per tonne
Land Preparation [a, b]			**Trellis System & Infrastructure** [a]		
Dolomite	kg	1.49	Steel posts	kg	0.16
Compost	kg	11.34	Wooden storage boxes	kg	4.1
Hay	kg	25.10			
Nutrient Management [a, c]			**Fuel Use** [a]		
N-fertilizer (from manure)	kg	1.60	Diesel	L	8.64
P-fertilizer (from manure)	kg	1.05			
K-fertilizer (from manure)	kg	1.20	**Farm Equipment** [a]		
Calcium chloride	kg	0.37	Tractor	kg	1.76
Boron	kg	0.03	Farm Implements	kg	0.88
Hay intensive organic, at farm	kg	4.43			
			Transport to Storage		
Pest and Disease Management [a, c]			Tractor, trailer	tkm	5.88
Copper, primary at refinery	kg	0.16			
Sulphur, from crude oil	kg	10.0			
Lime sulphur	kg	1.13			

a. Inputs were calculated as a weighted average of inputs reported by 10 responding conventional producers, where the total tonnage of apples produced in 2010 was used as the weighting factor.

b. ‘Land preparation’ inputs encompass all inputs used for orchard establishment, and on a frequent periodic basis (e.g., every 5 years) but less than annually.

c. ‘Nutrient management’ includes all reported inputs applied on an annual basis.

d. Emissions from active ingredients in pesticides to air (10%), water (1%), and soil (85%) were calculated according to values in Audsley (2003).

Table 5. Transportation scenarios

Location	Mode of transport	km from Kentville, NS
A) Halifax, Nova Scotia	Transport truck (28t)*	103
B1) Montreal, Quebec	Transport truck (28t)	1275
B2) Montreal, Quebec	Freight rail	1275
C) Houston, Texas	Transport truck (28t)	4167
D) London, England	Freight ship, transport truck (28t)	4638 (ship) + 250 (truck)

Table 6. Recent (2011) and hypothetical energy inputs to Nova Scotia electricity generation

Energy source	2011 Actual (%)	Renewable (scenario E1) (%)	Natural gas (scenario E2) (%)
Coal	57	34	0
Natural Gas	20	20	54
Hydro & Tidal	10	21	21
Wind	7	19	19
Other (imported oil & power)	6	6	6

Table 7. Life cycle impact assessment results of 2010 conventional Nova Scotian apple production to farm-gate and Halifax retail-gate per tonne of apples produced/delivered.

	GWP	POFP	AP	FEP	MEP	MDP	FDP	CED	HTCP	HTNCP	ETP
	(kg CO_2 eq)	(kg NMVOC)	(kg SO_2 eq)	(kg P eq)	(kg N eq)	(kg Fe eq)	(kg oil eq)	(MJ)	(CTUh)	(CTUh)	(CTUe)
Land prep,[1]	7.69E+00	1.13E-02	8.15E-02	1.63E-03	3.94E-03	1.11E-01	6.72E-01	1.06E+02	1.61E-10	3.55E-10	5.92E-01
(%)*	**12.0%**	**1.9%**	**5.6%**	**2.6%**	**1.8%**	**1.2%**	**3.2%**	**9.7%**	**0.3%**	**0.1%**	**0.0%**
Nutrient & Fert.[2] **(%)***	1.12E+01	1.10E-02	9.77E-01	3.43E-02	1.66E-01	1.45E-01	1.86E+00	8.19E+01	2.80E-10	6.07E-10	3.36E-03
	17.5%	**1.9%**	**66.5%**	**53.9%**	**77.5%**	**1.6%**	**9.0%**	**7.5%**	**0.5%**	**0.2%**	**0.0%**
Crop mgmt.[3]	1.37E+01	5.35E-02	1.01E-01	2.47E-02	2.64E-02	5.17E+00	6.90E+00	3.52E+02	5.66E-08	2.37E-07	6.96E+03
(%)*	**21.4%**	**9.2%**	**6.9%**	**38.7%**	**12.3%**	**55.7%**	**33.3%**	**32.1%**	**94.7%**	**93.7%**	**100.0%**
Infrastructure	1.32E+00	5.16E-03	6.78E-03	1.04E-03	-5.00E-04	1.88E+00	3.88E-01	8.16E+01	1.06E-10	2.16E-09	-6.88E-04
(%)*	**2.1%**	**0.9%**	**0.5%**	**1.6%**	**-0.2%**	**20.2%**	**1.9%**	**7.4%**	**0.2%**	**0.9%**	**0.0%**
Machinery	3.63E+00	1.73E-02	1.30E-02	2.03E-03	5.73E-04	1.99E+00	1.41E+00	7.73E+01	2.62E-10	3.27E-09	1.10E-02
(%)*	**5.7%**	**3.0%**	**0.9%**	**3.2%**	**0.3%**	**21.4%**	**6.8%**	**7.0%**	**0.4%**	**1.3%**	**0.0%**
Fuel use	2.65E+01	4.86E-01	2.89E-01	0.00E+00	1.78E-02	0.00E+00	9.47E+00	3.98E+02	2.33E-09	9.56E-09	3.29E-02
(%)*	**41.4%**	**83.2%**	**19.7%**	**0.0%**	**8.3%**	**0.0%**	**45.8%**	**36.3%**	**3.9%**	**3.8%**	**0.0%**
Total Orchard Production	6.41E+01	5.84E-01	1.47E+00	6.37E-02	2.14E-01	9.29E+00	2.07E+01	1.10E+03	5.98E-08	2.53E-07	6.96E+03
(%)**	**23.2%**	**46.4%**	**54.1%**	**44.6%**	**84.1%**	**67.2%**	**24.1%**	**26.8%**	**84.2%**	**95.9%**	**99.9%**
Transport to Storage	3.77E+00	2.80E-02	1.80E-02	0.00E+00	9.20E-04	0.00E+00	1.37E+00	5.76E+01	1.15E-11	7.79E-12	3.92E-03
(%)**	**1.4%**	**2.2%**	**0.7%**	**0.0%**	**0.4%**	**0.0%**	**1.6%**	**1.4%**	**0.0%**	**0.0%**	**0.0%**
Storage and Packing	2.00E+01	7.17E-02	5.76E-02	4.15E-03	4.63E-03	2.68E+00	8.86E+00	4.65E+02	1.39E-09	7.52E-09	3.51E+00
(%)**	**7.3%**	**5.7%**	**2.1%**	**2.9%**	**1.8%**	**19.4%**	**10.3%**	**11.4%**	**2.0%**	**2.8%**	**0.1%**
Electricity for Storage	1.73E+02	4.35E-01	1.09E+00	7.37E-02	3.02E-02	1.07E+00	4.85E+01	2.20E+03	4.45E-09	2.33E-09	6.54E-02
(%)**	**62.9%**	**34.6%**	**40.2%**	**51.5%**	**11.9%**	**7.7%**	**56.6%**	**53.6%**	**6.3%**	**0.9%**	**0.0%**
Transport to Halifax	1.45E+01	1.39E-01	8.12E-02	1.41E-03	4.76E-03	7.72E-01	6.35E+00	2.83E+02	5.40E-09	9.16E-10	3.90E-02
(%)**	**5.3%**	**11.1%**	**3.0%**	**1.0%**	**1.9%**	**5.6%**	**7.4%**	**6.9%**	**7.6%**	**0.3%**	**0.0%**
Total LC to Halifax Retail	**2.76E+02**	**1.26E+00**	**2.71E+00**	**1.43E-01**	**2.54E-01**	**1.38E+01**	**8.58E+01**	**4.10E+03**	**7.10E-08**	**2.64E-07**	**6.96E+03**

Notes: 1) Land preparation; 2) Nutrients and fertilizers; 3) Crop management (i.e. synthetic pesticides); (%)* = Relative contribution per tonne of apples from cradle-to-farm-gate; (%)** = Relative contribution per tonne of apples from cradle-to-Halifax-retail-gate.

Table 8. Life cycle impact assessment results of 2010 organic Nova Scotian apple production to farm-gate and Halifax retail-gate per tonne of apples produced/delivered.

	GWP	**POFP**	**AP**	**FEP**	**MEP**	**MDP**	**FDP**	**CED**	**HTCP**	**HTNCP**	**ETP**
	(kg CO_2 eq)	(kg NMVOC)	(kg SO_2 eq)	(kg P eq)	(kg N eq)	(kg Fe eq)	(kg oil eq)	(MJ)	(CTUh)	(CTUh)	(CTUe)
Land prep,[1]	9.27E+00	2.83E-02	3.98E-01	2.97E-03	1.56E-02	7.49E-01	8.71E-01	5.30E+02	5.11E-10	2.52E-09	5.69E-03
(%)*	**12.7%**	**4.4%**	**13.1%**	**5.4%**	**4.5%**	**5.9%**	**3.4%**	**30.0%**	**12.2%**	**4.7%**	**5.3%**
Nutrient & Fert.[2]	1.76E+01	1.42E-02	2.23E+00	3.71E-02	3.07E-01	1.62E-01	2.29E+00	1.85E+02	2.86E-10	5.46E-10	4.57E-03
(%)*	**24.1%**	**2.2%**	**73.5%**	**67.1%**	**88.9%**	**1.3%**	**9.0%**	**10.5%**	**6.8%**	**1.0%**	**4.3%**
Crop mgmt.[3]	6.92E+00	2.52E-02	5.22E-02	8.51E-03	1.53E-03	5.20E+00	8.07E+00	3.48E+02	1.39E-10	3.01E-08	2.73E-02
(%)*	**9.4%**	**3.9%**	**1.7%**	**15.4%**	**0.4%**	**41.2%**	**31.7%**	**19.7%**	**3.3%**	**55.9%**	**25.4%**
Infrastructure	3.63E-01	1.72E-03	1.30E-03	1.57E-04	7.16E-05	3.20E-01	1.16E-01	4.86E+01	3.50E-11	3.79E-11	2.46E-04
(%)*	**0.5%**	**0.3%**	**0.0%**	**0.3%**	**0.0%**	**2.5%**	**0.5%**	**2.8%**	**0.8%**	**0.1%**	**0.2%**
Machinery	1.17E+01	5.62E-02	4.21E-02	6.54E-03	1.84E-03	6.19E+00	4.57E+00	2.51E+02	8.28E-10	1.08E-08	3.63E-02
(%)*	**16.0%**	**8.8%**	**1.4%**	**11.8%**	**0.5%**	**49.1%**	**17.9%**	**14.2%**	**19.7%**	**20.1%**	**33.8%**
Fuel use	2.73E+01	5.13E-01	3.10E-01	0.00E+00	1.92E-02	0.00E+00	9.56E+00	4.01E+02	2.39E-09	9.83E-09	3.33E-02
(%)*	**37.2%**	**80.3%**	**10.2%**	**0.0%**	**5.6%**	**0.0%**	**37.5%**	**22.8%**	**57.1%**	**18.3%**	**31.0%**
Total Orchard Production	7.32E+01	6.38E-01	3.03E+00	5.53E-02	3.45E-01	1.26E+01	2.55E+01	1.76E+03	4.19E-09	5.38E-08	1.07E-01
(%)**	**25.9%**	**49.1%**	**71.0%**	**41.0%**	**89.6%**	**72.2%**	**28.4%**	**37.2%**	**27.0%**	**82.8%**	**2.9%**
Transport to Storage	1.82E+00	1.54E-02	1.01E-02	4.38E-04	5.64E-04	3.21E-01	6.00E-01	3.10E+01	7.83E-11	4.14E-10	3.51E-03
(%)**	**0.6%**	**1.2%**	**0.2%**	**0.3%**	**0.1%**	**1.8%**	**0.7%**	**0.7%**	**0.5%**	**0.6%**	**0.1%**
Storage and Packing	2.00E+01	7.17E-02	5.76E-02	4.15E-03	4.63E-03	2.68E+00	8.86E+00	4.65E+02	1.39E-09	7.52E-09	3.51E+00
(%)**	**7.1%**	**5.5%**	**1.3%**	**3.1%**	**1.2%**	**15.4%**	**9.9%**	**9.8%**	**8.9%**	**11.6%**	**94.2%**
Electricity for Storage	1.73E+02	4.35E-01	1.09E+00	7.37E-02	3.02E-02	1.07E+00	4.85E+01	2.20E+03	4.45E-09	2.33E-09	6.54E-02
(%)**	**61.3%**	**33.5%**	**25.5%**	**54.6%**	**7.8%**	**6.1%**	**54.0%**	**46.3%**	**28.7%**	**3.6%**	**1.8%**
Transport to Halifax	1.45E+01	1.39E-01	8.12E-02	1.41E-03	4.76E-03	7.72E-01	6.35E+00	2.83E+02	5.40E-09	9.16E-10	3.90E-02
(%)**	**5.1%**	**10.7%**	**1.9%**	**1.0%**	**1.2%**	**4.4%**	**7.1%**	**6.0%**	**34.8%**	**1.4%**	**1.0%**
Total LC to Halifax Retail	**2.83E+02**	**1.30E+00**	**4.27E+00**	**1.35E-01**	**3.85E-01**	**1.75E+01**	**8.98E+01**	**4.74E+03**	**1.55E-08**	**6.50E-08**	**3.73E+00**

Notes: 1) Land preparation; 2) Nutrients and fertilizers; 3) Crop management (i.e. non-synthetic pesticides); (%)* = Relative contribution per tonne of apples from cradle-to-farm-gate; (%)** = Relative contribution per tonne of apples from cradle-to-Halifax-retail-gate.

Table 9: Field level emissions from application of manure, fertilizer, and liming materials.

Orchard system	Emissions from Manure, Fertilizers & Liming Materials [a]	kg of Emissions (per tonne)
Conventional orchards (crop yield: 23.66)	CO_2 (from lime in land prep.)	3.29
	CO_2 (from lime in nutrient mgmt.)	0.53
	CO_2 (from urea in nutrient mgmt.)	0.22
	N_20 to air	0.02
	NO to air	0.02
	NH_3 to air	0.38
	NO_3 to water	0.56
	P_2O_5 to water	0.03
Organic orchards (crop yield: 11.88)	CO_2	0.71
	N_20 to air	0.04
	NO to air	0.03
	NH_3 to air	0.86
	NO_3 to water	0.97
	P_2O_5 to water	0.03

a. Field level emissions for nitrogen, phosphorus, and carbon dioxide were calculated using methods employed by Point and colleagues (2012) and Pelletier (2006). See Table 1 and Keyes (2013) for further details.

Table 10. Transportation and improvement scenario analyses results per tonne of conventional apples delivered

	GWP	POFP	AP	FEP	MEP	MDP	FDP	CED	HTCP	HTNCP	ETP
	(kg CO_2 eq)	(kg NMVOC)	(kg SO_2 eq)	(kg P eq)	(kg N eq)	(kg Fe eq)	(kg oil eq)	(MJ)	(CTUh)	(CTUh)	(CTUe)
A: Kentville to Halifax [a]	2.76E+02	1.26E+00	2.71E+00	1.43E-01	2.54E-01	1.38E+01	8.58E+01	4.10E+03	7.10E-08	2.64E-07	6.96E+03
% Transport [d]	**5.3%**	**11.1%**	**3.0%**	**1.0%**	**1.9%**	**5.6%**	**7.4%**	**6.9%**	**7.6%**	**0.3%**	**0.0%**
B1: Kentville to Montreal [a]	4.41E+02	2.84E+00	3.64E+00	1.59E-01	3.09E-01	2.26E+01	1.58E+02	7.32E+03	1.32E-07	2.75E-07	6.96E+03
% Transport [e]	**40.8%**	**60.6%**	**27.6%**	**11.0%**	**19.1%**	**42.3%**	**49.7%**	**47.9%**	**50.5%**	**4.1%**	**0.0%**
B2: Kentville to Montreal [b]	3.11E+02	1.41E+00	2.89E+00	1.73E-01	2.66E-01	1.97E+01	9.47E+01	4.77E+03	6.84E-08	2.67E-07	6.96E+03
% Transport [e]	**16.2%**	**20.4%**	**9.0%**	**18.4%**	**6.2%**	**33.9%**	**16.1%**	**20.1%**	**4.2%**	**1.5%**	**0.0%**
C: Kentville to Houston [a]	8.48E+02	6.75E+00	5.92E+00	1.99E-01	4.42E-01	4.43E+01	3.36E+02	1.53E+04	2.84E-07	3.00E-07	6.96E+03
D: Kentville to London [f]	3.46E+02	2.23E+00	3.84E+00	1.54E-01	2.90E-01	1.57E+01	1.12E+02	5.29E+03	7.95E-08	2.66E-07	6.96E+03
% Change [f]	**-59.2%**	**-67.0%**	**-35.1%**	**-22.7%**	**-34.5%**	**-64.6%**	**-66.8%**	**-65.3%**	**-72.0%**	**-11.4%**	**0.0%**
% Transport [g]	**24.5%**	**49.8%**	**31.5%**	**7.9%**	**13.8%**	**16.7%**	**28.9%**	**27.9%**	**17.5%**	**1.1%**	**0.0%**
E1: 40% Renewable energy scenario	2.19E+02	1.11E+00	2.39E+00	1.14E-01	2.43E-01	1.39E+01	7.16E+01	3.68E+03	7.07E-08	2.64E-07	6.96E+03
% Change [h]	**-20.4%**	**-11.8%**	**-11.9%**	**-20.5%**	**-4.4%**	**0.6%**	**-16.6%**	**-10.3%**	**-0.5%**	**-0.1%**	**0.0%**
E2: Natural gas scenario	1.84E+02	9.72E-01	2.33E+00	7.03E-02	2.28E-01	1.35E+01	7.01E+01	3.61E+03	7.46E-08	2.64E-07	6.96E+03
% Change [h]	**-33.4%**	**-22.7%**	**-14.1%**	**-50.8%**	**-10.3%**	**-2.4%**	**-18.3%**	**-12.0%**	**5.0%**	**-0.2%**	**0.0%**
F: Hydropower scenario	6.91E+02	6.55E+00	4.92E+00	1.27E-01	4.17E-01	4.44E+01	2.95E+02	1.42E+04	2.88E-07	2.99E-07	6.96E+03
% Change [i]	**-18.5%**	**-3.0%**	**-16.9%**	**-36.2%**	**-5.6%**	**0.4%**	**-12.4%**	**-7.1%**	**1.5%**	**-0.4%**	**0.0%**

a. Via transport truck

b. Via freight rail

c. Via freight ship and transport truck

d. Relative contribution of transport in cradle-to-Halifax retail baseline model (%)

e. Relative contribution of transport in cradle-to-Montreal-retail model (%)

f. Percentage change to life cycle emissions between scenario C (transport to Houston, TX) and D (transport to retail in the U.K.)

g. Relative contribution of transport in cradle-to-London-retail model (%)

h. Percentage change to life cycle emissions between Halifax baseline (A) and scenario E1 and E2

i. Percentage change to life cycle emissions between scenario C and F

Figure 1. System boundaries of the apply supply chain of Nova Scotia

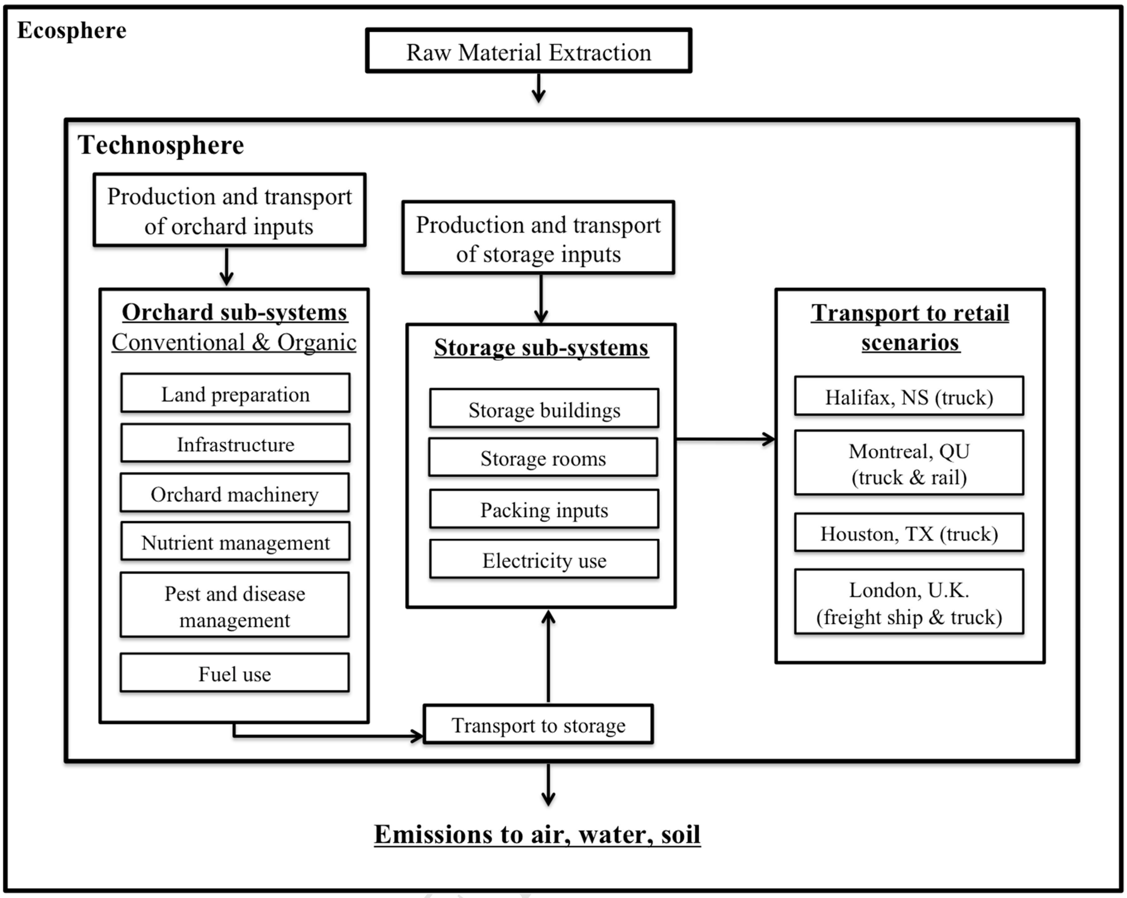


Figure 2. Global warming potential of transportation scenarios modeled

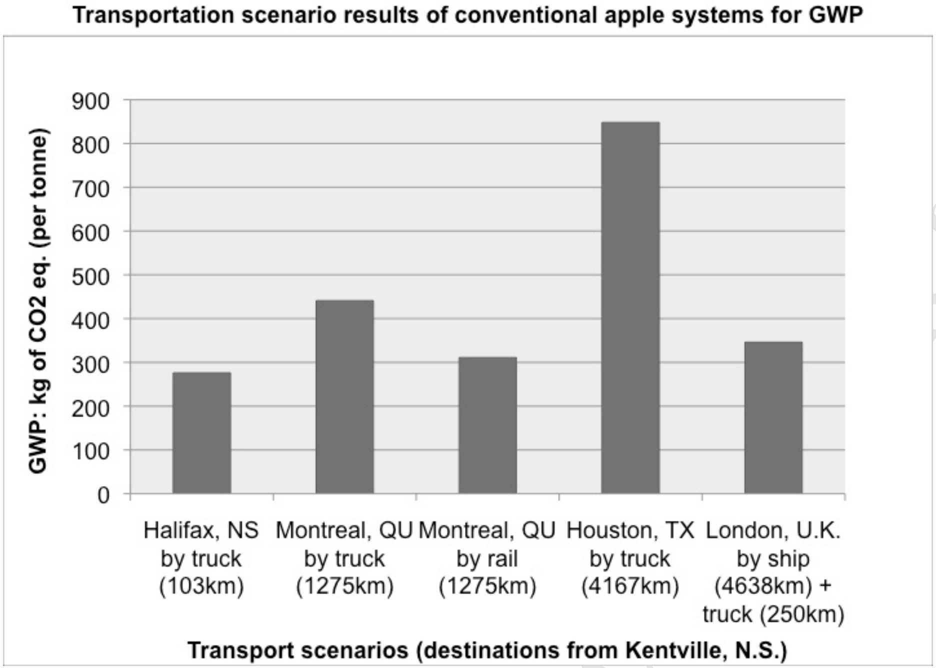
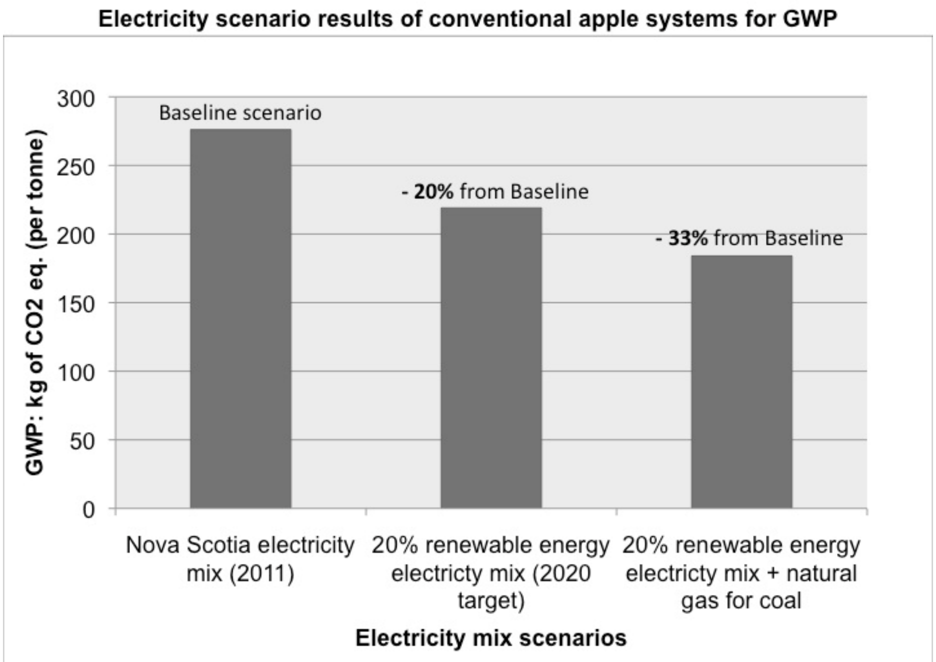


Figure 3. Global warming potential of electricity scenarios modeled



Highlights

- Conventional and organic apple supply chains in Nova Scotia were modeled and evaluated through LCA.
- On-orchards hotspots include fuels, fertilizers, and inputs and emissions of pest management.
- Coal-based electricity inputs led to significant contributions from storage systems.
- Transport via freight ship and rail is favourable over shipment of apples by transport truck.