

# **Growing Compact and Going Compact**

by

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## AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

## STATEMENT OF CONTRIBUTIONS

This thesis follows the manuscript option for master's students in the School of Planning at the University of Waterloo. This thesis consists of two manuscripts, both of which are intended for journal submission and may be adapted in response to peer review.

For all chapters of this thesis, I (Gaurang Khandelwal) am the principal author. I designed the research methods and analytical criteria for both manuscripts based on literature review and supervisory guidance from Dr. Leia Minaker and Dr. Goretty Dias, conducted all the data collection and analysis, and wrote 85% of the content for both manuscripts. The remaining 15% reflects the written edits and additions contributed by Dr. Leia Minaker and Dr. Goretty Dias.

As the primary supervisor, Dr. Leia Minaker contributed supervision and conceptual guidance, and supported the development of the research questions, approach, and analytical framework for both manuscripts. Dr. Minaker provided written feedback and edits most substantively to the second manuscript, "Perceived Barriers and Facilitators for Compact Agriculture in Canada: An Exploration of Multi-sector Key Informant Perspectives". Co-supervisor Dr. Goretty Dias also provided feedback and edits to the thesis, most substantively to the first manuscript, "Compact Agriculture versus Conventional Agriculture: Learnings from a Comparative Life Cycle Assessment".

## ABSTRACT

The food system is a major contributor towards climate change and global environmental deterioration. Agriculture has evolved manifold over the years and use of technology in food production has resulted in highly controlled-environment agricultural practices. The sustainability of such practices is still under question and so is its implementation in urban areas.

The overarching purpose of this thesis is to enable informed decisions to be made with respect to compact agriculture, which is essentially a hi-tech, high-density, and high-yielding agricultural practice within a completely closed environment. The thesis comprises of two manuscripts. The first is a comparative life cycle assessment (LCA) of compact agriculture with conventional agriculture for the City of Toronto, Canada. The second is a multi-sector key informants' perception on the barriers and facilitators of implementing compact agriculture in Canada.

Overall, the thesis concludes that conventional agriculture is better than compact agriculture at present. However, with the world rapidly urbanizing, cities sprawling over arable land, technology advancing at an exponential pace, and cleaner forms of energy production being adopted, things could change quickly, and compact agriculture could become an important future focus for food systems. Decision-makers are recommended to recognize and explicitly define compact agriculture in official plans and zoning bylaws. They are also recommended to compare life cycle impacts of proposed compact agriculture businesses with business as usual scenario. Businesses, on the other hand, are suggested to strive to provide a net positive socio-economic and environmental benefit to the community. Researchers are recommended to consider the limitations and scope of this study when undertaking future research.

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# CHAPTER 1: INTRODUCTION

This chapter serves as an introduction to guide this thesis. The first section provides an overarching background and explains the problem context. This is followed by a brief explanation of the thesis' purpose. Lastly, there is an overview of the subsequent chapters of this thesis, which includes the literature review, two manuscript chapters, and a conclusions chapter.

## 1.1 BACKGROUND

Many researchers have acknowledged the multifunctional character of the food system (Morgan, 2009; Pothukuchi & Kaufman, 2000; Weidner, Yang, & Hamm, 2019). The current food system “has profound impacts on a host of different sectors” (Morgan, 2009, p.341) and is a major contributor towards global environmental deterioration (Springmann et al., 2018; Weidner et al., 2019). The environmental impacts of the food system are often associated with “climate change, land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems” (Springmann et al., 2018, p.519). Twenty to thirty percent of the total environmental impact caused by humans is estimated to be attributable to agriculture (Tukker & Jansen, 2006, as cited in Hartmann & Siegrist, 2017) which is about 80%-86% of the overall food system impact in terms of emissions (Vermeulen, Campbell, & Ingram, 2012).

Though agriculture has been the bedrock of human civilization and is often considered as the onset of the age of mankind – the “Anthropocene” (Ruddiman, 2003; Tilman, Cassman, Matson, Naylor, & Polasky, 2002), it has evolved manifold over the years. The conventional form of agriculture, also referred to as traditional or field farming, adopted methods of intensive farming to take on a modern industrialized version. With the growing importance of sustainability matters, agriculture is becoming more of an urban matter and as

such, discourse on urban agriculture has been gaining momentum (Chou, 2017; Despommier, 2010; Martellozzo et al., 2014). Efficient integration of urban agriculture within the compact urban form of cities to make them more self-sufficient, sustainable, and resilient is becoming extremely important.

The inclusion of various technologies has enabled highly controlled agricultural practices (Nelkin & Caplow, 2008; Zeleny, 2012). Some interesting terminologies have been put forward like plant factories (Kozai, 2013; Takatsuji, 1987), building-integrated agriculture (Caplow, 2009), vertical farming (Bailey, 1915; Despommier, 2010), skyfarming (Germer et al., 2011), and zero-acreage or z-farming (Specht et al., 2014). This study coins the concept of “compact agriculture” which is considered to be an urban agricultural practice with completely closed exposure utilizing hydroponics, aquaponics, or aeroponics as growing medium for the purpose of sharing, preparing, retailing, or wholesaling for human consumption. Concepts like vertical farms, plant factories, and shipping container farms where the growth environment is human regulated are included within this idea understanding, while concepts such as farming on walls and rooftops or in greenhouses and community gardens where the environment may only be partially controlled are excluded. As such, compact agriculture is anticipated to be hi-tech and having high-density and high-yielding capabilities.

Compact agriculture, as a subset of urban agriculture and indoor agriculture, can have many benefits. Efficient use of land and resources, reduced ecological and carbon footprint, reduced food miles, reduced building energy use, reduced wastage, improved biodiversity and soil quality, increase year-round yields, improved air quality, protection from erratic weather conditions, and improved resiliency are some of the frequently mentioned advantages of compact agricultural forms (Goldstein, Hauschild, Fernández, & Birkved, 2016b). One of the most mentioned positive outcomes from implementation of these concepts in urban areas is food security for future generations in purview of rising urban

population and constraints of prime agricultural land (Caplow, 2009; Despommier, 2010; Germer et al., 2011; Specht et al., 2014).

However, compact agriculture can also have some downsides from an environmental perspective. Increased energy use and GHG emissions in compact agriculture point at the negative impacts (Benis et al., 2017a; Burés, 2013; Gruia, 2011; Harbick & Albright, 2016; He & Lee, 2013; Kozai, 2013; Nishizawa, 2014; Specht et al., 2014; Winiwarter et al., 2014). Indoor farming is also not suitable for resource intensive crops, grains, and trees. However, most negative impacts can be mitigated if non-conventional forms of energy are maximized in compact agriculture or more efficient technology is used (Gruia, 2011; He & Lee, 2013; Specht et al., 2014).

The risks and benefits associated with the compact forms of agriculture lacks strong empirical evidence and requires further assessment (Al-Chalabi, 2015). Even though literature talks about the positive and negative impacts compact agricultural forms can have, people are unsure on how sustainable it actually is and can be. Further, discussions on this topic are largely focused on the associated effects of operations but do not consider the barriers and facilitators faced by various stakeholders in Canada.

## **1.2 RESEARCH PURPOSE, OBJECTIVES AND QUESTIONS**

The overarching purpose of this study is to enable cities to make informed decisions with respect to compact agriculture implementation. More empirical evidence on compact agriculture can help with respect to decisions. Finding whether compact agriculture is beneficial or detrimental from an environmental perspective and how it can be improved in the future can help this discourse. Therefore, one of the objectives of this research is to compare compact agriculture with conventional agriculture from an environmental standpoint.

On the other hand, decoding the barriers faced by various stakeholders in the compact agricultural space can help identify the enabling attributes of cities for compact agriculture. As such, another objective of this study is to determine the barriers and facilitators for compact agriculture from stakeholders' perspectives. The economic and social perspectives are of focus here.

Successful implementation of compact agriculture, however, can be location specific. Therefore, this study focusses on the City of Toronto as a subject city. However, learnings from this research may be transferable to other cities. The City of Toronto was chosen because it is the largest city in Canada by population. As per Census 2016, the City of Toronto had a population of 2.73 million translating to a population density of 4334.4 persons per square kilometer (Statistics Canada, 2017).

The specific research questions that guide this thesis are -

1. How does compact agriculture compare to conventional agriculture in terms of life cycle environmental impacts?
2. How do stakeholders perceive barriers and facilitators to establishing and maintaining compact agriculture in urban areas in Canada?

### **1.3 THESIS ORGANIZATION**

This thesis follows the manuscript-style option for master's students in the School of Planning at the University of Waterloo. Following this introductory chapter, the thesis is structured as follows:

#### *Chapter 2: Literature Review*

This chapter contains a comprehensive overview of literature relevant to this thesis, which is sectioned into an overview of the urban food production system, and agriculture and

the compact urban form of cities. Key findings from the literature are presented and lead to a discussion of the research questions that guide this thesis.

*Chapter 3: Manuscript 1 – Compact Agriculture versus Conventional Agriculture:  
Learnings from a comparative Life Cycle Assessment*

This chapter is based on a life cycle assessment of lettuce production by compact agriculture and conventional agriculture for the City of Toronto. It presents comparative findings from an environmental perspective for compact agriculture.

*Chapter 4: Manuscript 2 – Perceived Barriers and Facilitators for Compact  
Agriculture in Canada: An Exploration of Multi-sector Key Informant Perspective*

This chapter describes findings from a series of qualitative interviews of key informants in the field of compact agriculture and focusses on the City of Toronto. It presents the state of compact agriculture in Canada and the City of Toronto, barriers to compact agriculture, facilitators and opportunities for compact agriculture, and characteristics of cities suitable for compact agriculture from key informants' perspectives.

*Chapter 5: Conclusions*

This chapter acts as an overarching discussion of results brought forth in each of the two manuscripts. The significance and links between these results are first discussed followed by limitations of this study and recommendations for future researchers, decision-makers, and businesses.

## CHAPTER 2: LITERATURE REVIEW

This chapter provides justification for the research topic. It sets the context around urban agriculture and compact urban agriculture forms from which the research questions emerge. This chapter will synthesize the current state of the literature on urban food production systems, their potential towards combating sustainability issues in compact urban settings, and the present status of compact agricultural practices in Canada.

### 2.1 METHOD TO SUPPORT LITERATURE REVIEW

The literature review started with an initial scan of urban indoor farming concepts, including vertical farming (Bailey, 1915; Despommier, 2010), plant-factories (Takatsuji, 1987), and building-integrated agriculture (Caplow, 2009). These concepts promote use of soilless growing technologies, such as hydroponics, aquaponics, or aeroponics in or on buildings rather than being cited at ground level and have also been referred to as controlled-environment agriculture (Benis & Ferrão, 2018). Advocates believe that these concepts have the potential to address social and environmental concerns in urban areas, while critics argue that the intensive capital and energy requirements limit their contribution towards the current urban food system (Goodman & Minner, 2019).

Three key themes were identified within the broad subject: the urban food production system; agriculture and the compact urban form of cities; and compact agriculture in Canada. A search strategy was created (Table 2-1) to support the review.

Table 2-1. Search strategy for literature review

Theme	Search Strategy
<b>Urban food production system</b>	“food system” AND urban AND (history OR future OR advances OR advancement OR development)
<b>Agriculture and the compact urban form of cities</b>	(“urban form” OR “compact city” OR “compact cities” OR “smart growth” OR “sustainable city”) AND agriculture
<b>Compact agriculture in Canada</b>	(“urban agriculture” OR “controlled environment agriculture” OR “vertical farming” OR “plant factories”) AND (policy OR regulation OR bylaw) AND Canada

The identified key words with respect to the themes were searched for as part of the article title, abstract, or key word in Scopus and Web of Science databases. Selection of articles was based on the relevance to the theme based on the title scan. In addition to the selected journal articles through the search strategy, reference list of the selected articles and sources which had cited the selected articles were also considered for inclusion in the review. Also, urban agriculture related policies and bylaws for Toronto, Vancouver, Calgary, Edmonton, and Winnipeg were scanned in this review to provide context for compact agriculture in Canadian cities.

## 2.2 URBAN FOOD PRODUCTION SYSTEM

### 2.2.1 THE FOOD SYSTEM AND ENVIRONMENT

The food system has been described as a chain of activities from production to consumption (as cited in Ericksen, 2008, p.235). Pothukuchi & Kaufman (2000, p.113) define it as “the chain of activities connecting food production, processing, distribution, consumption, and disposal as well as all the associated regulatory institutions and activities”. Kasper et al. (2017) explain the interconnections between the five components of production, processing, distribution, consumption, and disposal (see Figure 2-1).

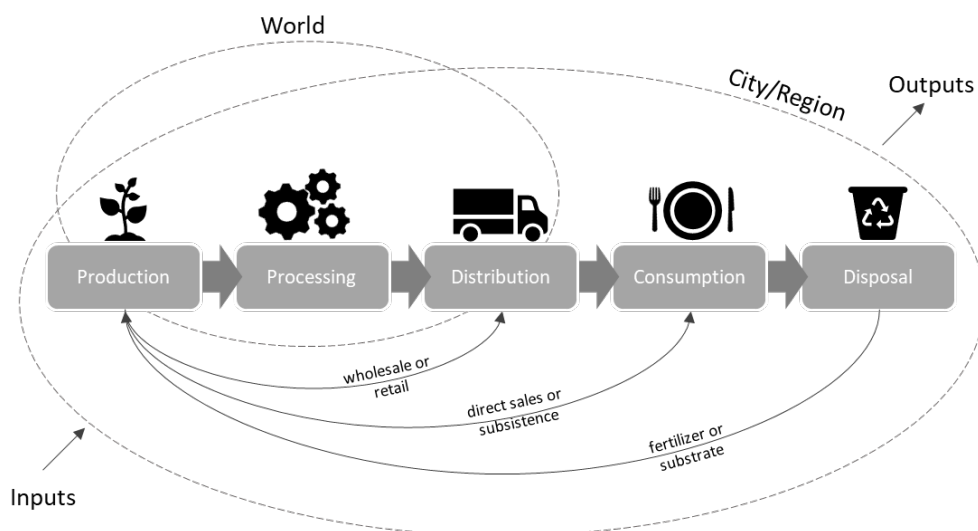


Figure 2-1. Components of the food system (adapted from Kasper et al., 2017; Toronto Public Health, 2015)



The modern food system has become highly industrialized (Ericksen, 2008; Kasper, Brandt, Lindschulte, & Giseke, 2017; Pothukuchi & Kaufman, 1999). Many researchers have acknowledged the multifunctional character of the food system (Morgan, 2009; Pothukuchi & Kaufman, 2000; Weidner et al., 2019). The current food system “has profound impacts on a host of different sectors” (Morgan, 2009, p.341) and is a major contributor towards global environmental deterioration (Springmann et al., 2018; Weidner et al., 2019). The environmental impacts of the food system are often associated with “climate change, land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems” (Springmann et al., 2018, p.519). A detailed review by Tukker & Jansen (2006) of 11 studies that analyzed the life cycle impacts of total societal consumption estimated twenty to thirty percent of the total environmental impact caused by humans to be attributable to food production (as cited in Hartmann & Siegrist, 2017). This in turn was estimated to be about 80%-86% of the overall food system impact in terms of emissions (Vermeulen et al., 2012). The remainder comes from pre-production (e.g. fertilizer and pesticide manufacturing) and post-production (e.g. storage and distribution) activities.

The literature provides substantial evidence of the food system activities resulting in high production of greenhouse gases (GHGs) and major contributions to climate change (Garnett, 2011; Lipper et al., 2014; Vermeulen et al., 2012; Willett et al., 2019). There has also been increasing recognition that the food system is bound to be affected by climate change (Niles et al., 2018; Tirado, Clarke, Jaykus, McQuatters-Gollop, & Frank, 2010; Vermeulen et al., 2012). This is not just limited to food production but also global food distribution, food safety hazards, and nutritional quality of foods. Apart from the constant state of flux between the food system and the environment, the food system also has profound effects on various other sectors such as social justice, public health, and economic development (Morgan, 2009). Considering the impacts of the food production system, innovation in the global food system to improve environmental sustainability is imperative in

the 21<sup>st</sup> century (Goodman & Minner, 2019; Weidner et al., 2019) and therefore understanding of the food system is important.

In terms of food production, the average North American farm is large in scale and industrial in nature: in Canada, the average farm was 778 acres in 2011, and 820 acres in 2016, in keeping with previous growth trends (Census of Agriculture, 2016). A limited number of crops typically dominate a particular farm that uses intensive agricultural inputs (Ericksen, 2008). The requirement of large sized arable land for agriculture coupled with lack of adequate space in urban areas has had food production to remain a largely rural subject. Agricultural production alone is responsible for about one-third of the total food loss volume globally (*Food wastage footprint*, 2013). The generation of waste at production stage has a high environmental impact. Principal employment in the food system has recently seen a shift away from the food production sector. Most of the employment today, especially in the developed countries, is in the food processing, packaging and retail industries (Ericksen, 2008).

Processing, which follows production of food, refers to the transformation of agricultural products comprising methods of preservation, industrial food processing and food preparation (Kasper et al., 2017). Food processing industries are most often located in proximity to the production activities in order to reduce economic costs related to transportation of agricultural produce.

Distribution of food, the process of transporting food from production and/or processing sites to consumers is critical in the food system. It also includes wholesale and retail avenues for consumer buying (Kasper et al., 2017). With over 55% of the world's population estimated to be residing within urban areas in 2018 (*World Urbanization Prospects: The 2018 Revision*, 2018), food today travels many miles before reaching the end consumer (Ericksen, 2008). Food miles and associated GHG emissions have also been

recognized as drivers of environmental change (Benis & Ferrão, 2018; Crush & Frayne, 2011; Ericksen, 2008; Horst, McClintock, & Hoey, 2017; Kasper et al., 2017).

“Consumption includes the preparation of food, food culture aspects, and the transformation into organic waste” (Kasper et al., 2017, p.1013). Many scholars have pointed out to the importance of changing consumer preferences and choices with respect to food in order to lower the environmental impact of the food system (Niles et al., 2018; Weber & Matthews, 2008; Westhoek et al., 2014). One common suggestion in the literature for reducing environmental impacts of the food system is promoting local food consumption among consumers since reduction in food miles reduces the environmental burden (Benis & Ferrão, 2018; Ericksen, 2008; Rothwell, Ridoutt, Page, & Bellotti, 2016). Other suggestions include turning over to sustainable options in terms of vegetarian food or insects (Hartmann & Siegrist, 2017).

Disposal refers to the management of food loss or food waste generated through all other components of the food system. Gustavson et al. (2011) estimate almost 30% of the global food produced to be lost or wasted at some point along the food supply chain (as cited in Principato, Ruini, Guidi, & Secondi, 2019). Wastage occurring during consumption stage is much more variable than that occurring during production, processing or distribution stages. Middle- and high-income regions waste between 31-39 percent while low-income regions waste only 4-16 percent at consumption stage (*Food wastage footprint*, 2013). Waste is either disposed of in land fills or transformed into a useful resource for further use (Kasper et al., 2017). Food waste is often associated with environmental repercussions, and therefore food waste management is an important component of the food system (Mohareb et al., 2017).

Food systems research has been a footnote in planning literature up until the start of the millennium (Pothukuchi & Kaufman, 1999). As agricultural activities are concentrated in the countryside, research on food systems has historically been a rural affair (Born & Purcell,

2006). However, agriculture in urban areas has always been present in the global south and is reappearing in the global north (Huang & Drescher, 2015a; Morgan, 2009). There has been growing popularity of food system localization in the past couple of decades. Many researchers have vouched for local food system to be a sustainable alternative to the existing situation (Allen, FitzSimmons, Goodman, & Warner, 2003; Benis & Ferrão, 2018; Blay-Palmer et al., 2018; Crush & Frayne, 2011; Fraser, Mabee, & Figge, 2005; Hinrichs, 2003; Horst et al., 2017; Kasper et al., 2017; Lerner & Eakin, 2011; Morgan, 2013; Pothukuchi & Kaufman, 1999; Salvador, 2019). Others, like Born & Purcell (2006), conversely, have suggested that local food system is no more likely to be sustainable than other systems and to avoid the 'local trap' while putting higher emphasis on matters of scale produced through social actors in food systems planning. The next section delves into the context of urban agriculture.

## **2.2.2 URBAN AGRICULTURE**

### *2.2.2.1 A Brief History*

Urban agriculture in contemporary planning times had a humble introduction through conception of the Garden City (illustrated in Figure 2-2) by Ebenezer Howard in 1898, wherein 5,000 acres of agricultural land doubling as a greenbelt was proposed around the city (Fishman, 2016; Pothukuchi & Kaufman, 2000). Howard (1898) understood the links between food and other community systems and therefore addressed all major aspects of the food system - production, processing, distribution, consumption, and waste management (as cited in Pothukuchi & Kaufman, 2000).

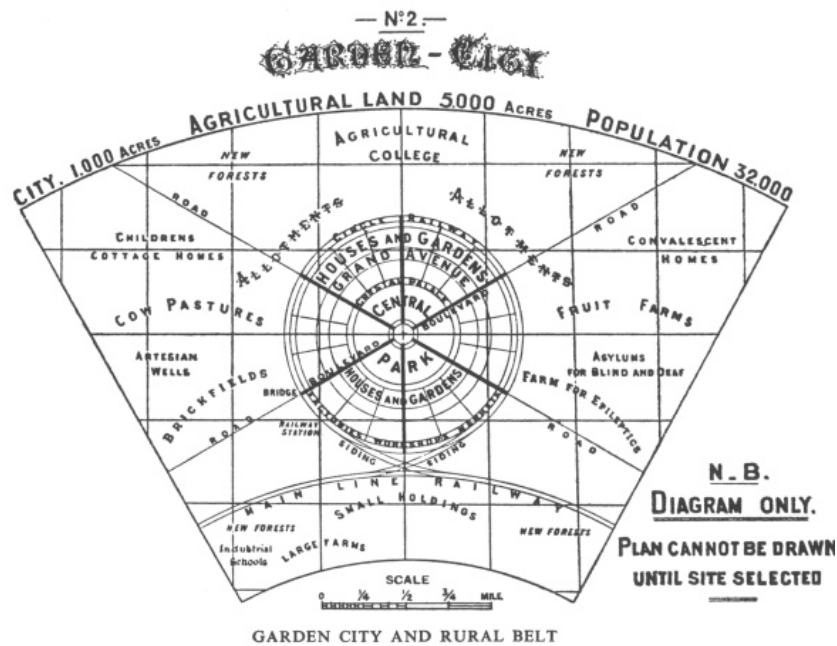


Figure 2-2. Garden City concept (Howard, 1898)

In North America, urban agriculture has roots in times of crisis. The United States government encouraged setting up of War Gardens and Victory Gardens during World War I and World War II respectively to increase food security and patriotism (Mok et al., 2014). Relief Gardens were promoted during the Great Depression of the 1930s in order to provide food, income and purpose to the unemployed (Bassett, 1981). The broader availability of food coupled with the consumerist lifestyles embraced after the war made backyard food production unnecessary. Interest in community and backyard gardens resurfaced in the late 1960s and early 1970s due to growing environmental awareness, counter-culture movement against consumerism, and economic uncertainty (Mok et al., 2014).

#### 2.2.2.2 Definitions and classifications

Urban agriculture is diverse in terms of its “scope, scale, type of access and for whom, participants, and goals” (Horst et al., 2017, p.280). Many scholars have defined urban agriculture in many different ways but the most common conceptual building blocks of urban agriculture are types of economic activities, food/non-food categories and sub-categories of

products, intra-urban and peri-urban character of location, types of areas where it is practiced, types of production systems, product destination, and production scale (Mougeot, 2000).

One of the most widely accepted definitions was provided by Smit, Nasr, & Ratta, in 1996 which was eventually adopted by the United Nations Development Program (UNDP).

They define urban agriculture as -

an industry that produces, processes, and markets food, largely in response to the daily demand of consumers within a town, city, or metropolis, on land and water dispersed throughout urban and peri-urban areas. Typically urban agriculture applies intensive production methods, frequently using and reusing natural resources and urban wastes, to yield a diverse array of land-, water-, and air-based fauna and flora, contributing to the food security, health, livelihood, and environment of the individual, household, and community (p.1).

This definition failed to recognize the non-food categories and sub-categories of products such as ornamental and agro-industrial plants like silk, tobacco etc. Mougeot (2000) provided a revised definition of urban agriculture as -

an industry located within (intra-urban) or on the fringe (peri-urban) of a town, a city or a metropolis, which grows or raises, processes and distributes a diversity of food and non-food products, (re-)using largely human and material resources, products and services found in and around that urban area, and in turn supplying human and material resources, products and services largely to that urban area (p.11).

Mougeot's (2000) definition better captured the essence of integrating agriculture with the urban eco-system. However, it missed to touch on the possible contributions of urban agriculture unlike Smit et al. (1996).

Due to the varied definitions of urban agriculture, categorization of urban agriculture features also differs. Authors have used certain basis for classifying urban agriculture. Table 2-2 summarizes the different classifications of urban agriculture where the primary focus has been on horticultural activities rather than animal husbandry. Mok et al. (2014) recognizes presence of three distinct scales of agriculture in urban systems. Goldstein et al. (2016a) classifies urban agriculture based on the integration within the surrounding urban system

(building integrated or ground based) and the conditioning required for the growing environment (conditioned/controlled or non-conditioned/uncontrolled). Mohareb et al., (2017) provides yet another classification of urban agriculture ordered by scale and sophistication of production. Benis & Ferrão (2018) classification seems to build on and further categorize Goldstein et al. (2016a) building-integrated-conditioned and building-integrated-non-conditioned typologies.

Table 2-2. Classification and basis of classification of urban agriculture

<b>Author</b>	<b>Basis of classification of urban agriculture</b>	<b>Classification</b>
(Mok et al., 2014)	Scale	Small commercial farms and community-supported agriculture Community gardens Backyard gardens Hybrid of two or more
(Goldstein et al., 2016c)	Integration within urban system and control on growth environment	Ground based non-conditioned Ground based conditioned Building-integrated non-conditioned Building-integrated conditioned
(Mohareb et al., 2017)	Scale and sophistication	Residential gardens Allotment and community gardens Rooftop/balcony agriculture Industry/residence-integrated greenhouses Vertical farms Peri-urban agriculture
(Benis & Ferrão, 2018)	Integration with built environment	Rooftop farms Rooftop greenhouses Vertically integrated greenhouses Vertical farms Shipping container farms

The Association for Vertical Farming (AVF) provides a comprehensive urban agriculture integration typology to categorise urban agriculture projects from around the world (Association for Vertical Farming, n.d.). They categorize projects based on seven parameters: organization type (grower, technology, institution, consultancy); organization size (start-up, small-medium with over 6 employees, established with over 40 employees); integration (holistic at time of building conception, retrofitted onto existing building, converted from existing building); placement (rooftop, interior, façade, underground, on-ground);

exposure (exposed, enclosed but utilizes sunlight, closed from all natural elements); growing medium (aeroponics, aquaponics, hydroponics, planter, containerized, intensive, extensive); and production purpose (share, teach, prepare, retail, wholesale, clean, heal, develop) (Figure 2-3).

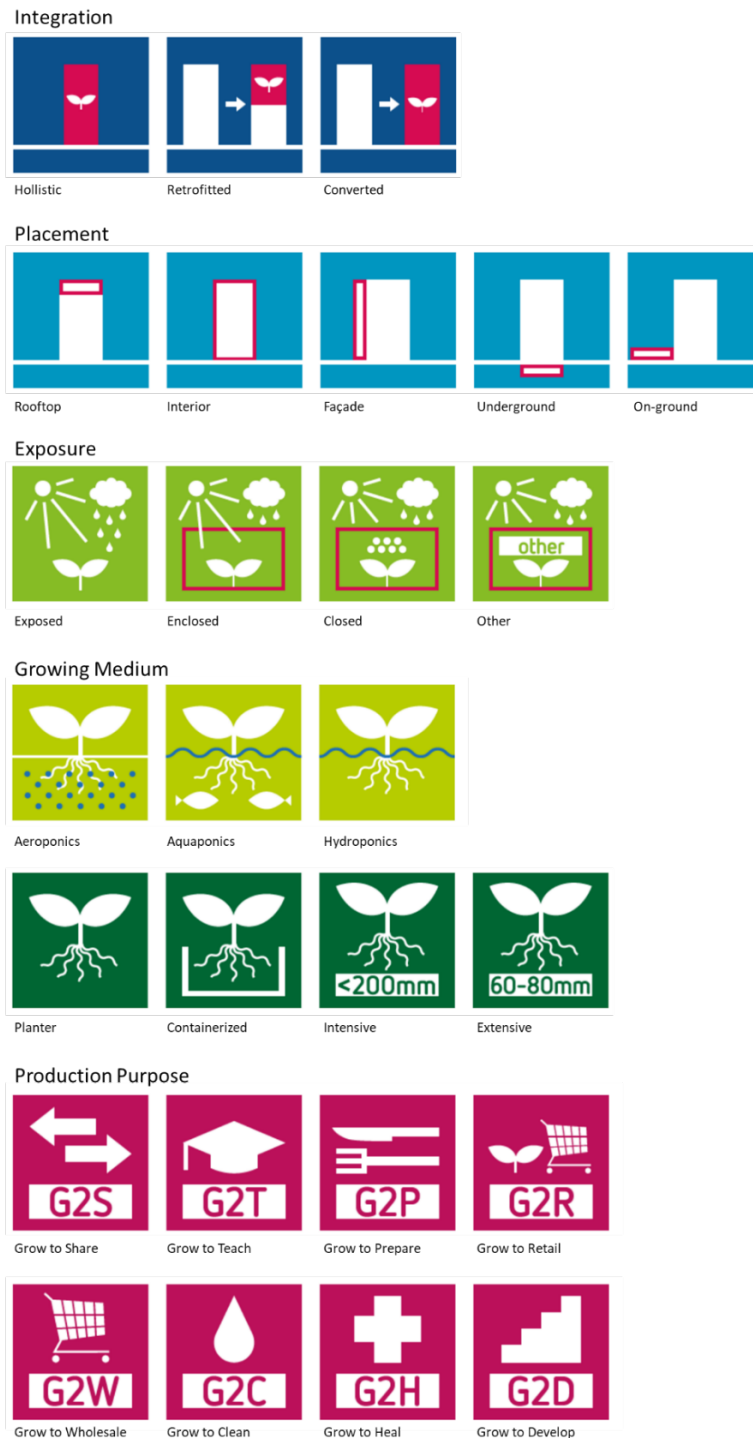


Figure 2-3. Urban agriculture integration typology by the Association for Vertical Farming (modified from “Urban Agriculture Integration Typology,” n.d.)



Due to the varied scope and different classifications of urban agriculture, there have been many different terminologies put forward with respect to somewhat similar concepts. This is particularly true in case of conditioned or controlled-environment agriculture where the growth environment is regulated through the use of artificial lighting and ventilation as well as the use of soilless growing technologies (Besthorn, 2013; Nelkin & Caplow, 2008; Pfeiffer, Silva, & Colquhoun, 2015; Zeleny, 2012). Some of the terminologies put forward are plant factories (Kozai, 2013; Takatsuji, 1987), building-integrated agriculture (Caplow, 2009), vertical farming (Bailey, 1915; Despommier, 2010), skyfarming (Germer et al., 2011), and zero-acreage or z-farming (Specht et al., 2014). The definitions of these concepts have been highlighted in Table 2-3.

Table 2-3. Different concepts of urban agriculture

Concept	Author	Definition
Plant factories	Takatsuji (1987) / Kozai (2013)	“Plant factory refers to a plant production facility consisting of 6 principal components: a thermally insulated and nearly airtight warehouse-like opaque structure, 4 to 20 tiers equipped with hydroponic culture beds and lighting devices such as fluorescent and LED lamps, air conditioners with air fans, a CO <sub>2</sub> supply unit, a nutrient solution supply unit with water pumps, and an environment control unit”
Building-integrated agriculture	Caplow (2009)	“Practice of locating high-performance hydroponic greenhouse systems on and in mixed-use buildings to exploit the synergies between the building environment and agriculture like energy and nutrient flows”
Vertical farming	Bailey (1915) / Despommier (2010)	“Concept of cultivating plants or animal life within skyscrapers or on vertically inclined surfaces”
Skyfarming	Germer et al. (2011)	“Indoor crop production within purpose-built, multi-storey buildings to satisfy the growing staple food demand while arresting rampant conversion of natural ecosystems into crop land”
Zero-acreage farming	Specht et al. (2014)	“All types of urban agriculture characterized by the non-use of farmland or open space”

This thesis focuses on the concept of “compact agriculture”. Defining in terms of AVF’s urban agriculture integration typology, compact agriculture is considered to be an urban agricultural practice with completely closed exposure utilizing hydroponics, aquaponics, or aeroponics as growing medium for the purpose of sharing, preparing, retailing, or wholesaling for human consumption. Concepts like vertical farms, plant factories, and shipping container farms where the growth environment is human regulated are included within this concept, while concepts such as farming on walls and rooftops or in greenhouses and community gardens where the environment may only be partially controlled are excluded. As such, compact agriculture is anticipated to be hi-tech and having high-density and high-yielding capabilities. The term ‘compact’ in compact agriculture is used to synchronize with the compact city concept discussed further in the subsequent section.

## **2.3 AGRICULTURE AND THE COMPACT URBAN FORM OF CITIES**

### **2.3.1 THE COMPACT CITY AND SUSTAINABILITY**

The ‘Compact City’ was conceptualized by Dantzig & Saaty (1973) and was a step forward on Le Corbusier’s high-density ‘Radiant City’. In short, the compact city introduced a way to develop cities to be more spacious, convenient, and accessible by more effective use of the third dimension (up and down) as well as the fourth dimension (around-the-clock use of facilities). The focus in the compact city concept is on compactness. Jabareen (2006) recognized this distinctive characteristic of the compact city and described it as being highly dense with a mix of land uses, diversity of activity, and emphasis on sustainable multimodal transportation. However, Jabareen (2006) also documented lower emphasis on matters of greening in the Compact City, which they consider crucial for an ideal sustainable urban form.

Studies on Compact Cities frequently refer to the savings in prime agricultural land but fail to reflect on food security and food accessibility issues (Gordon & Richardson,

1997a; Neuman, 2005). Compact Cities function on the linear structure, deriving majority of their food supply from outside city limits. The ecological footprint of Compact Cities, therefore, is not actually confined and sprawls outwards to the rural areas. Despite the environmental issues currently being exacerbated by the food system, some have argued that agriculture can actually contribute positively to sustainability agendas in urban areas (Swanwick, Dunnett, and Woolley, 2003 as cited in Jabareen, 2006). The philosophy behind this is to limit a city's ecological footprint (Beatley, 2012; Lehmann, 2010). One of the ways to achieve this is restructuring the society from a linear system to a circular system.

A linear system or economy is generally summarized as a take-make-consume-dispose one (Sariatli, 2017; "Vertical Farming Infographics," 2017) which entails taking the resources needed, making goods to be sold, consuming that is needed, and then disposing everything that is not needed. A circular system or economy, on the other hand, is a looped make-use-recycle one. It "preserves the value added in products for as long as possible and virtually eliminates waste" (European Commission, n.d.) and therefore embodies the idea of sustainability.

Andersson (2000) mentions that the concept of sustainability has only been applied to a certain extent to agricultural production (food and non-food). Today, the food system is a large user of energy and natural resources which contributes heavily towards all kinds of pollution. It is essential to have a more ecological perspective in food production. Therefore, it is important to evaluate the environmental impact for all stages of the food system: production; processing; distribution; consumption; and disposal. One way to assess environmental impacts of the food system is using a life cycle assessment (LCA) approach.

LCA is a tool that can be used to analyse and assess the environmental load caused by a product, process, or activity throughout its lifecycle (Andersson, 2000; Shiina, Hosokawa, Roy, Nakamura, et al., 2011). It is an important tool which assists industries, authorities, and consumers in informed decision-making. The purpose of LCA studies can be

to compare alternative products, processes or services; compare alternative life cycles for a certain product or services; or identify parts of the life cycle where environmental performance can be improved. These studies require adherence to the methodology articulated by the International Organization for Standardization (ISO) 14040-14044 standard series.

### **2.3.2 COMPACT AGRICULTURE IN COMPACT CITIES**

With the sustainability of conventional agriculture clearly important, agriculture is becoming increasingly recognized as an urban matter as well. As such, discourse on urban agriculture has been gaining momentum (Chou, 2017; Despommier, 2010; Martellozzo et al., 2014). Efficient integration of urban agriculture within the compact urban form of cities to make them more self-sufficient, sustainable, and resilient is becoming extremely important.

The International Union for Conservation of Nature (IUCN) talks about three dimensions of sustainability in their report (IUCN, 2006): environmental, social, and economic. The social and economic dimensions are considered as a single dimension for the purpose of this study. This section discusses findings from literature on the environmental and socio-economic impacts of compact agriculture (vertical farms, plant factories, and shipping container farms) compared to traditional field, greenhouse, and traditional urban (community gardens, rooftop gardens) agriculture.

#### *2.3.2.1 Environmental dimension*

Many studies note an increased energy use in the case of vertical farms or plant factories compared to conventional agriculture, community gardens and greenhouses (Benis et al., 2017b; Burés, 2013; Gruia, 2011; Harbick & Albright, 2016; He & Lee, 2013; Kozai, 2013; Nishizawa, 2014; Specht et al., 2014; Winiwarter et al., 2014). Completely opaque farms, which fully rely on artificial lighting, use more energy than farms which use solar

lighting (Benis et al., 2017b; Harbick & Albright, 2016; Nishizawa, 2014). Burés (2013) and Specht et al. (2014) note how overall energy use in vertical farms is offset if energy saved in transportation of produce is considered. Gruia (2011), He & Lee (2013), and Specht et al. (2014) also acknowledge the fact that impact of energy consumption can be drastically reduced if more non-conventional sources of energy such as solar, wind, biofuel, and biomass are used and building synergies are exploited.

In terms of resource use, studies show significantly fewer resources used in vertical farms or plant factories compared to conventional agriculture, community gardens, and greenhouses (Benis et al., 2017b; He & Lee, 2013; Joo & Jeong, 2017; Kozai, 2013; Nichols, 2017; Specht et al., 2014; Winiwarter et al., 2014). This is evidenced through recycling of resources (Joo & Jeong, 2017; Specht et al., 2014; Winiwarter et al., 2014) and reduction in use of water (He & Lee, 2013; Nichols, 2017) as well as pesticides, herbicides and fertilizers (Kozai, 2013). Benis et al. (2017) and Kozai (2013), however, acknowledge the fact that vertical farms or plant factories have an added accountability of recycling structural components such as lights, air conditioners, and thermal insulations once they have reached the end of their service.

Research comparing greenhouse gas (GHG) emissions between compact and traditional agriculture shows less consistent findings. A simulation study by Benis et al. (2017) found that completely opaque vertical farms have higher GHG emissions than vertical farms with windows, hi-tech rooftop gardens, and low-tech rooftop gardens. On the other hand, Specht et al. (2014) and Burés (2013) indicate massive reductions in emissions related to distribution. They argue that having proximity to consumers lowers the food miles thereby reducing harmful emissions. Harbick & Albright (2016) claims that vertical farms or plant factories have higher carbon footprint than greenhouses producing equivalent yields, specifically when they use simple reheat HVAC systems. Nichols (2017), Harbick & Albright (2016), and Winiwarter et al. (2014) acknowledge the fact that vertical farms or plant factories have a considerably less geographical footprint. In addition, Specht et al. (2014)

recognizes that immense reduction in land requirement can be translated in to release of existing farmland that could serve for bio-energy, afforestation and nature protection, and/or more extensive agricultural production. Existing research consistently finds that compact agriculture, although resource efficient, is highly energy intensive. However, researchers have differing opinions on the environmental impact due to energy consumption and GHG emissions. This is because some researchers consider production stage whereas others consider both production and distribution stage for comparison.

### *2.3.2.2 Socio-economic dimension*

Vertical farms or plant factories have higher yields per area compared to conventional farming (Benis et al., 2017b; Dong et al., 2015; Epting, 2016; He, 2017; He & Lee, 2013; Jon Schneller, Schofield, Frank, Hollister, & Mamuszka, 2015; Kozai, 2013; Nichols, 2017; Nishizawa, 2014; Specht et al., 2014; Touliatos, Dodd, & McAinsh, 2016; Winiwarter et al., 2014). This is attributed to adoption of soilless growing techniques and lower harvest time with potential for year-round production. At the same time, greenhouses can have comparable yields if similar technologies are used (Dong et al., 2015; He, 2017; Kozai, 2013). There can be 3 to 30 times increase of yields in vertical farms or plant factories compared to conventional farming depending on the type of crop and technology used (Benis et al., 2017b). Kozai (2013) and Winiwarter et al. (2014) even argue for a 200-fold overall increase in yields considering vertical stacks across multiple floors in a vertical farm.

Food security is cited as a primary benefit of urban agricultural activities. He & Lee (2013), Joo & Jeong (2017) and Winiwarter et al. (2014) note that urban farming can help improve food security throughout the year regardless of the erratic climate which can affect production via traditional methods. Epting (2016) discusses how urban agriculture can enable people to control their food supply. He further argues that vertical agricultural projects can support incremental food system reform. Referring to food security in Singapore, He & Lee (2013) demonstrated how vertical farming can diminish a country's reliance on

vegetable imports and thus enhance its national food security. Controlled environment agriculture can also result in reduction of the many infectious plant diseases which, however, depends on efficient management (Winiwarter et al., 2014). On the other hand, there have been certain exclusionary practices and disparities as well. Guthman (as cited in Specht et al., 2014), for example, has argued that the local food movement has a tendency to locate or distribute to areas of relative wealth and cater to relatively well-off consumers rather than meeting needs of lower-income consumers.

Burés (2013) and Joo & Jeong (2017) acknowledge that controlled environment farming can guarantee freshness of produce to the consumers as crop production can be based on pre-orders and plans. Graff (as cited in Specht et al., 2014) and Winiwarter et al. (2014) state that fewer use of pesticides, herbicides and fertilizers in vertical farms or plant factories could reduce health risks associated with high exposure to agrochemicals. However, there may be a challenge for indoor farms that employ soil-less growing techniques as these are not fully accepted by the community at large. This is because people prefer “naturally” grown food (Specht et al., 2014; Specht, Weith, Swoboda, & Siebert, 2016).

Vertical farms or plant factories can be an economic advantage for urban areas (Specht et al., 2014). According to Kozai (2013), working environment of indoor farms is comfortable and enhances people’s will to work. As such, indoor farms can be providers for new employment and can also become new marketing opportunities to attract people and businesses into cities. Although indoor farms can be beneficial for a city’s economic growth and development, employment generation by these farms is debatable. Integration of automation in indoor farms can reduce employment opportunities by eliminating human reliance (Joo & Jeong, 2017).

Joo & Jeong (2017) and Specht et al. (2014) touch upon the fact how different forms of urban agriculture can provide an opportunity for city dwellers to observe and study plant

growth, food and nutrition as well as empower children to make educated choices about their impact on the environment. Indoor farming techniques have an advantage over outdoor farming techniques such as community gardens or rooftop gardens as they can provide year-round learning possibilities and can be integrated in the school curriculum (Jon Schneller et al., 2015). However, the human interaction in indoor farms needs to be regulated and managed properly to avoid unwanted spread of diseases in indoor plants (Winiwarter et al., 2014).

### *2.3.2.3 Opportunities and challenges for compact agriculture*

Efficient use of land and resources, reduced ecological and carbon footprint, reduced food miles, reduced building energy use, reduced wastage, improved biodiversity and soil quality, increase year-round yields, improved air quality, protection from erratic weather conditions, and improved resiliency are some of the frequently mentioned advantages of compact agricultural forms (Goldstein et al., 2016b). One of the most mentioned positive outcomes from implementation of these concepts in urban areas is food security for future generations in purview of rising urban population and constraints of prime agricultural land (Caplow, 2009; Despommier, 2010; Germer et al., 2011; Specht et al., 2014).

However, other scholars disagree with the purported benefits. They argue that the issue of food scarcity is more of a result of poverty and unequal distribution of food (Gordon & Richardson, 1997b). They further contend that urban agriculture does not solve equity issues and in fact causes exclusionary effects resulting in gentrification of urban areas. Some also contend that energy consumption and GHG emissions in controlled environment agriculture is much higher than in conventional agriculture. This is because the amount of electricity used towards provision of artificial lighting is much more than that is saved through reduction in food miles (Li, Li, & Yang, 2016).

There are also some obvious challenges for successful implementation of these concepts in cities. These are high investment costs, lack of public acceptance, availability of



required technologies, zoning issues, maintenance issues, lack of experienced workers, and competition with economically attractive alternate land uses (Specht et al., 2014; Specht, Siebert, & Thomaier, 2016). Indoor farming is also not suitable for all crops. Growing grains does not result in as much savings of resources as growing vegetables and fruits does. It is also not viable to incorporate slow growing trees within indoor farms. Critics, therefore, believe that investments in other solutions may yield bigger returns.

The discussion on opportunities and challenges of the compact forms of agriculture lacks strong empirical evidence in favor or against the claims that the proponents and critics make (Al-Chalabi, 2015). Though there may be challenges with respect to implementation of compact agriculture, there is potential for generating successful scenarios in cities and therefore exploring realistic implementation strategies is a useful exercise.

### **2.3.3 COMPACT AGRICULTURE IN CANADIAN CITIES**

Many scholars acknowledge the importance of planning practice in the success of urban agriculture (Mendes, Balmer, Kaethler, & Rhoads, 2008; Thibert, 2012). Literature provides strategies for traditional forms of urban agriculture, however, implementing compact agricultural forms in cities is a new topic and thus missing from existing research. Some of the recommendations provided in case of urban agriculture, community gardens, and rooftop gardens can be adapted for compact agriculture in cities. The suggestions are primarily geared towards municipal policy level changes (Desjardins, Lubczynski, & Xuereb, 2011; Huang & Drescher, 2015b). Including urban agriculture in plans, policies, and by-laws is essential to remove legal barriers. Scholars also recommend to have explicit documentation of urban agriculture in plans and policies with preference of having its own land use designation (Mendes et al., 2008). In addition, idea for a comprehensive food strategy provides direction for successful execution of urban agriculture initiatives.

Stakeholder identification and engagement is important for any successful policy. Huang & Drescher (2015) identify six key stakeholders in the field of urban agriculture. These are citizens, non-government organizations, public authorities, municipal departments, academic and research institutions, and private businesses. The roles of stakeholder are further characterized into either of regulation, facilitation, provision, or partnership. They further recognize that public authorities undertake all four roles for shaping urban agriculture. This holds true for compact agriculture as well.

The largest cities of the five most populated English-speaking census metropolitan areas (CMAs) in Canada were explored for policies and by-laws with respect to compact agriculture. Cities in Quebec were left out of this assessment as Quebec is essentially a French-speaking province. These were Toronto (Ontario), Vancouver (British Columbia), Calgary (Alberta), Edmonton (Alberta), and Winnipeg (Manitoba). The review illustrates the disparity amongst Canadian cities towards compact agriculture. This is discussed below.

#### *2.3.3.1 City of Toronto*

The Toronto Food Policy Council (TFPC) was established in 1991 to advise the City of Toronto on food policy issues. In 2002, Toronto's Official Plan first expressed the support for community and rooftop gardens as important elements for creating beautiful, healthy and active cities and for engaging diverse communities. The closest reference to compact agriculture in Toronto's Official Plan is in terms of vertical agriculture permitted in core employment areas (policy 4.6.1 in City of Toronto, 2002). However, the Toronto's Official Plan does not explicitly define urban agricultural terms till date.

Furthermore, Toronto's zoning by-law defines agricultural use as "the use of premises for growing and harvesting plants or raising animals, fowl, fish, or insects" (City of Toronto, 2013, p.322). It also defines market garden as "premises used for growing and harvesting vegetables, fruits, flowers, shrubs, trees or other horticultural products for the purpose of sale" (City of Toronto, 2013, p.328). However, the zoning bylaw also fails to

define vertical agriculture (City of Toronto, 2013). Agricultural use is permitted in the Open Space – Natural Zone (clause 90.20.20.10), while market garden is permitted in the Residential Apartment Commercial Zone (clause 15.20.20.20) under the condition (clause 15.20.20.100) that it may not be used for the growing and harvesting of shrubs or trees for the purpose of sale and the Utility and Transportation Zone (clause 100.10.20.10).

### *2.3.3.2 City of Vancouver*

Though the City of Vancouver is under the process of preparing a city-wide plan, it already has ambitious urban agriculture initiatives. The Vancouver Food Strategy is a plan to create a just and sustainable food system for the city. It defines urban agriculture as “the production and harvesting of fruits and vegetables, raising of animals, or cultivation of fish for local consumption or sale within and around cities” (City of Vancouver, 2013, p.51). The City of Vancouver identifies different types of urban agriculture including community gardens, urban farming, hobby beekeeping, backyard hens, and edible landscaping.

Urban farming differs from other types of urban agriculture and is defined as “urban food production for the primary purpose of revenue generation, and (which) may be operated on a for-profit, non-profit or social enterprise model” (City of Vancouver, 2013, p.58). The raising of livestock for sale is not included. Further, in 2016, the City of Vancouver categorized urban farms into class A and class B (City of Vancouver, 2016). The urban farm class B is where compact agriculture can make way into the City of Vancouver. Permitted in the industrial, commercial, and historical area zones of Vancouver, it can be small or large, can have soil or soilless growing, can sell produce from the site, and include a building or greenhouse.

The City of Vancouver’s, *Greenest City: 2020 Action Plan* calls for an increase of urban farms to achieve economic, social and environmental objectives (City of Vancouver, 2015). Further, the Urban Farm Guidelines used in conjunction with the Zoning and Development By-law and the License By-law, assist both urban farm applicants to apply as

well as City staff to evaluate applications by providing details on suitability of urban farms in Vancouver and ensuring that urban farms meet policy and regulations.

#### *2.3.3.3 City of Calgary*

City of Calgary's Municipal Development Plan has a city-wide policy that calls for shaping a compact urban form (Section 2.2 in *The City of Calgary, 2009*). This policy envisions for complete communities. It mentions that, among other requirements, communities should be planned with the idea of and provide spaces for community gardens and local food production (Section 2.2.4 in *The City of Calgary, 2009*). Urban agriculture is supported but not defined in the Municipal Development Plan.

*Calgary Eats: A Food System Assessment and Action Plan for Calgary*, published in 2012, builds on community-led efforts to create a healthy, equal and sustainable food system with a goal for every citizen to have access to local, healthy and environmentally friendly food (*The City of Calgary, 2012*). It talks extensively about food production and identifies different forms of urban agriculture including community gardens, institutional gardens, small-scale commercial and semi-commercial, large-scale agro-enterprises, multi-functional farms, and rooftop gardens and vertical farming. However, none of these forms are what compact agriculture comprises of. The term vertical farming is used to define the growing of plants on, up, or against the façade of a building and in conjunction with rooftop gardens.

The City of Calgary's Land Use By-law defines urban agriculture as well as food production separately (Land Use Bylaw Sustainment Team, Development & Building Approvals, & Planning Implementation, 2007). Urban agriculture means a use where plants are grown outdoors for a commercial purpose (Policy 320.1 in Land Use Bylaw Sustainment Team, Development & Building Approvals, & Planning Implementation, 2007). Whereas, food production means a use where plants are grown to produce food in a building which may include hydroponics, aquaponics, and vertical growing and where all of the processes

and functions associated with the use are contained in a fully enclosed building (Policy 198.1 in Land Use Bylaw Sustainment Team, Development & Building Approvals, & Planning Implementation, 2007). Food production is where compact agriculture may fall under in Calgary's land use. Further, food production category requires business licensing for operation and is permitted in commercial districts, mixed-use district, and some of the centre city and centre city east village districts (The City of Calgary, n.d.).

#### *2.3.3.4 City of Edmonton*

The City of Edmonton has a resilient food and agriculture system that contributes to the local economy and the overall cultural, financial, social and environmental sustainability. The City of Edmonton's Municipal Development Plan envisions increasing access to local food and building resilience into the food and urban agriculture system (section 10.1.1 in The City of Edmonton, 2010). It defines urban agriculture as all agricultural growing opportunities within the municipality's boundaries and includes commercial farming operations, community gardens, allotment gardens, vertical gardens, edible landscaping, green roofs, aquaculture, animal husbandry and apiculture but excludes stockyards, feedlots and intensive livestock operations. However, the types of urban agriculture mentioned are not defined in the Municipal Development Plan.

On the other hand, "fresh - Edmonton's Food and Urban Agriculture Strategy" provides a high-level strategy to guide Edmonton towards the vision of a resilient food and agriculture system (The City of Edmonton, 2012). It is supportive of and explicitly defines certain terminologies which relate to compact agriculture such as non-soil food production, hydroponics, aquaponics and vertical growing.

Further, the City of Edmonton's Zoning Bylaw, amended in 2016, identifies three categories under urban agriculture: urban outdoor farms; urban gardens; and urban indoor farms (The City of Edmonton, 2017). Compact agriculture is relatable to the urban indoor farm terminology. It is defined in section 7.5 (7) as "the cultivation and harvesting of plant

and/or animal products primarily within enclosed buildings for the primary purpose of wholesale or retail sales”. It may include vertical farms, hydroponic systems and aquaponic systems but not livestock operations, rural farms, recreational acreage farms, urban outdoor farms, urban gardens or the cultivation or growth of cannabis.

#### *2.3.3.5 City of Winnipeg*

City of Winnipeg’s Municipal Development Plan does not touch upon the overarching topic of urban agriculture but talks about and defines community gardens (The City of Winnipeg, 2010). Further ‘Complete Communities’, one of four Direction Strategies of Winnipeg’s Municipal Development Plan, supports local food production in Winnipeg. The plan does not identify, nor it relates to compact agriculture practices. Further, the City of Winnipeg’s Zoning Bylaw also does not define urban agriculture land use other than community gardens (The City of Winnipeg, 2006).

#### *2.3.3.6 Summary*

Despite the rising popularity and acceptance of urban agriculture (community and rooftop gardens in particular), use of technologies such as hydroponics, aquaponics, and aeroponics has been infrequently mentioned in regulatory documents for food production in large Canadian cities. While Vancouver, Calgary, and Edmonton enable provision of compact agriculture practices through their city-wide plans and zoning bylaws, Winnipeg does not recognize compact agriculture at present. It is surprising to note that the City of Toronto allows for vertical agriculture but does not define it in its official plan or zoning bylaws.

## **2.4 KEY FINDINGS**

Four key findings emerged from the literature synthesized above. First, compact agriculture is a novel form of urban agriculture, and the extent to which it can reduce environmental impacts associated with food systems is unknown. Second, compact

agriculture is purported to offer many socio-economic benefits to cities. Third, risks and benefits of compact agriculture are worth exploring given the potential for reducing environmental impacts and for improving food security. Fourth, despite the rising popularity, cities pose regulatory barriers for implementation of compact agriculture in Canada. Each of these key findings will be discussed in greater detail below.

First, compact agricultural forms are relatively novel within the realm of urban agriculture and are still being explored for improvements. Minor variations in implementation has given rise to many different terms for compact agricultural concept (Caplow, 2009; Despommier, 2010; Germer et al., 2011; Specht et al., 2014). However, the different concepts have common characteristics such as a highly controlled environment, use of artificial lighting, and use of growth technologies such as hydroponics, aquaponics, or aeroponics (Caplow, 2009; Despommier, 2010; Germer et al., 2011; Nelkin & Caplow, 2008; Nichols, 2017; Zeleny, 2012). Discussion on this topic in Canada and similar cold countries has been limited but gradually growing. Literature points to positive as well as negative impacts of compact agriculture from an environmental perspective. Reduced resource use and reduced food miles are some potentially positive impacts (Benis et al., 2017b; He & Lee, 2013; Joo & Jeong, 2017; Kozai, 2013; Nichols, 2017; Specht et al., 2014; Winiwarter et al., 2014). On the other hand, increased energy use and GHG emissions point at negative impacts (Benis et al., 2017b; Burés, 2013; Gruia, 2011; Harbick & Albright, 2016; He & Lee, 2013; Kozai, 2013; Nishizawa, 2014; Specht et al., 2014; Winiwarter et al., 2014). Moreover, the potentially large carbon footprint but small geographical footprint of indoor agriculture is also debatable by proponents and critics (Harbick & Albright, 2016; Nichols, 2017; Specht et al., 2014; Winiwarter et al., 2014). However, these negative impacts can be mitigated if non-conventional forms of energy are maximized in compact agriculture or more efficient technology is used (Gruia, 2011; He & Lee, 2013; Specht et al., 2014). Also, it is extremely important to appropriately implement and manage compact agricultural farms to ease the health risks associated with improperly treated wastewater, contaminated soil, and spread of

food-borne diseases in densely populated areas (Specht et al., 2014; Winiwarter et al., 2014).

Second, urban agriculture, including compact agriculture, has many positive impacts from a socio-economic standpoint. Most of the literature highlights improved crop productivity in controlled environment, improved food security in urban areas, and additional opportunities for community involvement and employment (Benis et al., 2017b; Burés, 2013; Dong et al., 2015; Epting, 2016; He, 2017; He & Lee, 2013; Jon Schneller et al., 2015; Joo & Jeong, 2017; Kozai, 2013; Nichols, 2017; Nishizawa, 2014; Specht et al., 2014; Touliatos et al., 2016; Winiwarter et al., 2014). In addition, food education through indoor agriculture provides long-term sustainability and health benefits for future generations (Jon Schneller et al., 2015; Joo & Jeong, 2017; Specht et al., 2014). On the other hand, there have been certain exclusionary practices and disparities as well. Guthman (2003) and Ackerman (2011) deliberate on how the local (urban) food movement has a tendency to locate or distribute to areas of relative wealth and thus cater to only relatively well-off consumers (as cited in Specht et al., 2014).

Third, the risks and benefits associated with compact agriculture need further assessment. There is lack of empirical evidence that supports the claims of proponents. Literature recognizes requirement of a full life cycle assessment for compact agriculture and comparison with conventional agriculture (Benis et al., 2017b; Kozai, 2013). Furthermore, evaluation of compact agriculture needs to be location specific. This is because cities which already have access to predominantly local produce may not be attractive for compact agriculture in lieu of energy consumption, while cities which do not have access to local produce may hold a viable proposition for compact agriculture as energy and wastage in transportation can be reduced and freshness of produce increased (Benis et al., 2017b; Burés, 2013; Specht et al., 2014).



Fourth, Canadian cities have regulatory hurdles for urban as well as compact agriculture. Where cities like Vancouver, Calgary, and Edmonton regulate the provision of compact agricultural farms in their respective jurisdictions, cities like Toronto and Winnipeg currently do not explicitly recognize these. These barriers can have negative impact on growth of compact agriculture businesses in the country.

## **2.5 RESEARCH QUESTIONS**

Taking cues from and identifying gaps in the existing body of knowledge on the topic, the overarching purpose of the research is identified to understand if compact agriculture is viable for urban areas in Canada. Because of the novel nature of the topic, two research questions were framed to guide this objective.

First, *in terms of life cycle environmental impacts, how does compact agriculture compare to conventional agriculture?* This research question will focus on the environmental dimension of compact agriculture.

Second, *how do different stakeholders perceive barriers and facilitators with respect to establishing and maintaining compact agriculture in urban areas in Canada?* This question stems from the need of assessing what will, what does, and what can make compact agriculture a success or failure in Canada. Regulatory and socio-economic factors are of particular focus in this question.

# CHAPTER 3: COMPACT AGRICULTURE VERSUS CONVENTIONAL AGRICULTURE: LEARNINGS FROM A COMPARATIVE LIFE CYCLE ASSESSMENT

Co-authored by Dr. Goretty Dias and Dr. Leia Minaker, who provided supervisory guidance and edits to written content.

## 3.1 ABSTRACT

The food system produces high levels of greenhouse gases (GHG) which contributes to climate change and global environmental deterioration. Agriculture has been the bedrock of human civilization and has evolved manifold over the years. Use of technology in food production has resulted in highly controlled-environment agricultural practices. The sustainability of such practices is still under question and so is its implementation in urban areas. This study explored the environmental sustainability of compact agriculture, which is essentially a hi-tech, high-density, and high-yielding agricultural practice within a completely closed environment. A life cycle assessment (LCA) framework was used to evaluate and compare compact agriculture with conventional agriculture. The study used a cradle-to-retail gate life cycle assessment (LCA) framework to evaluate and compare compact agriculture with conventional agriculture. 1 kg of packaged romaine lettuce at retail gate in the City of Toronto, Canada was taken as the functional unit for the study. The study found that compact agriculture production at present has a higher environmental impact potential than conventional agriculture production. It also illustrates electricity consumption to be the highest contributor towards environmental impact potential for compact agriculture where a shift to cleaner sources of electricity production will make compact agriculture more environmentally sustainable.

*Keywords: Life cycle assessment, compact agriculture, shipping container farm, vertical farm, plant factory, lettuce, Canada, Toronto*

## 3.2 INTRODUCTION

Many researchers have acknowledged the multifunctional character of the food system (Morgan, 2009; Pothukuchi & Kaufman, 2000; Weidner et al., 2019). The food system is defined as “the chain of activities connecting food production, processing, distribution, consumption, and disposal as well as all the associated regulatory institutions and activities” (Pothukuchi & Kaufman, 2000, p.113). The current food system “has profound impacts on a host of different sectors” (Morgan, 2009, p.341) and is a major contributor towards global environmental deterioration (Springmann et al., 2018; Weidner et al., 2019). The environmental impacts of the food system are often associated with “climate change, land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems” (Springmann et al., 2018, p.519). A detailed review by Tukker & Jansen (2006) of 11 studies that analyzed the life cycle impacts of total societal consumption estimated twenty to thirty percent of the total environmental impact caused by humans to be attributable to food production (as cited in Hartmann & Siegrist, 2017). This in turn was estimated to be about 80%-86% of the overall food system impact in terms of emissions (Vermeulen et al., 2012) while the remainder comes from pre-production (e.g. fertilizer and pesticide manufacturing) and post-production (e.g. storage and distribution) activities.

The literature provides enough evidence of the food system activities resulting in high production of greenhouse gases (GHG) which aids in climate change (Garnett, 2011; Lipper et al., 2014; Vermeulen et al., 2012; Willett et al., 2019). There has also been an increasing recognition that the food system is in turn bound to be affected by climate change (Niles et al., 2018; Tirado et al., 2010; Vermeulen et al., 2012). This is not just limited to food production but also the global food distribution, food safety hazards, and nutritional quality of foods. Apart from the constant state of flux between the food system and the environment, the food system also has profound effects on various other sectors such as social justice, public health, and economic development (Morgan, 2009). Considering the impacts of the

food production system, innovation in the global food system to improve environmental sustainability is imperative in the 21<sup>st</sup> century (Goodman & Minner, 2019; Weidner et al., 2019).

Though agriculture has been the bedrock of human civilization and is often considered as the onset of the age of mankind – the “Anthropocene” (Ruddiman, 2003; Tilman et al., 2002), it has evolved manifold over the years. The conventional form of agriculture, also referred to as traditional or field farming, adopted methods of intensive farming to take on a modern industrialized version. With the growing importance of sustainability matters, agriculture is becoming more of an urban matter and as such, discourse on urban agriculture has been gaining momentum (Chou, 2017; Despommier, 2010; Martellozzo et al., 2014). Efficient integration of urban agriculture within the compact urban form of cities to make them more self-sufficient, sustainable, and resilient is becoming extremely important.

The inclusion of various technologies has enabled highly controlled agricultural practices (Nelkin & Caplow, 2008; Zeleny, 2012). Some interesting terminologies have been put forward like plant factories (Kozai, 2013; Takatsuji, 1987), building-integrated agriculture (Caplow, 2009), vertical farming (Bailey, 1915; Despommier, 2010), skyfarming (Germer et al., 2011), and zero-acreage or z-farming (Specht et al., 2014). This study coins the concept of “compact agriculture”.

Compact agriculture, in this study, is considered to be an urban agricultural practice with completely closed exposure utilizing hydroponics, aquaponics, or aeroponics as growing medium for the purpose of sharing, preparing, retailing, or wholesaling for human consumption. Concepts like vertical farms, plant factories, and shipping container farms where the growth environment is human regulated are included within this understanding, while concepts such as farming on walls and rooftops or in greenhouses and community gardens where the environment may only be partially controlled are excluded. As such,

compact agriculture is anticipated to be hi-tech, having high-density and high-yielding capabilities.

Compact agriculture, as a subset of urban agriculture and indoor agriculture, has many benefits. Efficient use of land and resources, reduced ecological and carbon footprint, reduced food miles, reduced building energy use, reduced wastage, improved biodiversity and soil quality, increase year-round yields, improved air quality, protection from erratic weather conditions, and improved resiliency are some of the frequently mentioned advantages of compact agricultural forms in the literature (Goldstein et al., 2016b). One of the most frequently mentioned positive outcomes from implementation of these concepts in urban areas is food security for future generations in purview of rising urban population and constraints of prime agricultural land (Caplow, 2009; Despommier, 2010; Germer et al., 2011; Specht et al., 2014).

However, compact agriculture can also have some downsides from an environmental perspective. Increased energy use and GHG emissions in compact agriculture point at the negative impacts (Benis et al., 2017b; Burés, 2013; Goldstein, Hauschild, Fernández, & Birkved, 2016a; Gruia, 2011; Harbick & Albright, 2016; He & Lee, 2013; Kozai, 2013; Nishizawa, 2014; Shiina, Hosokawa, Roy, Nakamura, et al., 2011; Specht et al., 2014; Winiwarter et al., 2014). Some scholars contend that because the amount of electricity used towards provision of artificial lighting is much more than that saved through reduction in food miles, energy consumption and GHG emissions in compact agriculture can be much higher than in conventional agriculture (Li et al., 2016). Indoor farming is also considered unsuitable for resource intensive crops, grains, trees. However, most negative impacts can be mitigated if non-conventional forms of energy are maximized in compact agriculture or more efficient technology is used (Gruia, 2011; He & Lee, 2013; Specht et al., 2014).

The risks and benefits associated with compact agriculture lacks strong empirical evidence and needs further assessment (Al-Chalabi, 2015). Further, the evaluation of

compact agriculture needs to be location specific. This is because cities which already have access to predominantly local produce may not be attractive for compact agriculture in lieu of energy consumption, while cities which do not have access to local produce may hold a viable proposition for compact agriculture as energy and wastage in transportation can be reduced and freshness of produce increased (Benis et al., 2017a; Burés, 2013; Specht et al., 2014).

Life cycle assessments (LCA) to compare environmental impact between compact agriculture and conventional agriculture have been suggested as important next steps in research (Benis et al., 2017a; Kozai, 2013). LCA is a comprehensive framework that can be used to analyse and assess the environmental load caused by a product, process, or activity throughout its lifecycle (Andersson, 2000; Shiina, Hosokawa, Roy, Nakamura, et al., 2011). It can also be used to compare alternative products, processes or services; compare alternative life cycles for a certain product or services; and identify parts of the life cycle where environmental performance can be improved. This study used an LCA framework to evaluate and compare compact agriculture with conventional agriculture.

### **3.3 METHODS**

This study used attributional LCA to quantify the cradle-to-retail gate environmental impacts of compact lettuce production in a shipping container and compare it with conventional lettuce production of lettuce consumed in the City of Toronto. The analysis of the environmental and energy performance of average shipping container lettuce production followed the ISO 14044 (ISO, 2006) LCA framework as described in the following sections.

#### **3.3.1 GOAL AND SCOPE DEFINITION**

The goal of this LCA study was to quantify the environmental and energy performance of producing leaf lettuce (romaine lettuce) within a shipping container and compare that with producing lettuce through conventional agriculture for consumption in the

City of Toronto. Specific goals included evaluating which of the two product systems has the least environmental impact and if there are trade-offs; and identifying the stage(s) in the life cycle for the two systems that contribute the most towards environmental impact and thus suggesting possible improvement scenario(s). Since the study was focused on two distinct agricultural systems with a common function of producing food for human consumption, the functional unit (FU) considered in this study was 1 kg of packaged leaf lettuce (romaine lettuce) at the point of sale in the City of Toronto.

This was a cradle-to-retail-gate study. The system boundaries for the study are illustrated in Figure 3-1 . Production, processing, and delivery of 1 FU to a grocery store (retail gate) in the City of Toronto was considered. Consumption and waste disposal post retail were excluded as they are independent of the two production systems and considered to be identical. The background processes included material supply, energy supply, and agricultural inputs before operations. Infrastructure for production and storage facilities and waste management at time of operations were excluded from the system boundaries for simplification purposes. However, it is recommended to be included for a more comprehensive LCA study. The foreground processes included the nursery, full production, and distribution operations for 1 FU. Since lettuce was the only end-product being considered for the two systems with hydroponics being utilized in case of compact agriculture, allocation was not necessary in the study. The two lettuce production systems are described further in subsequent sections.

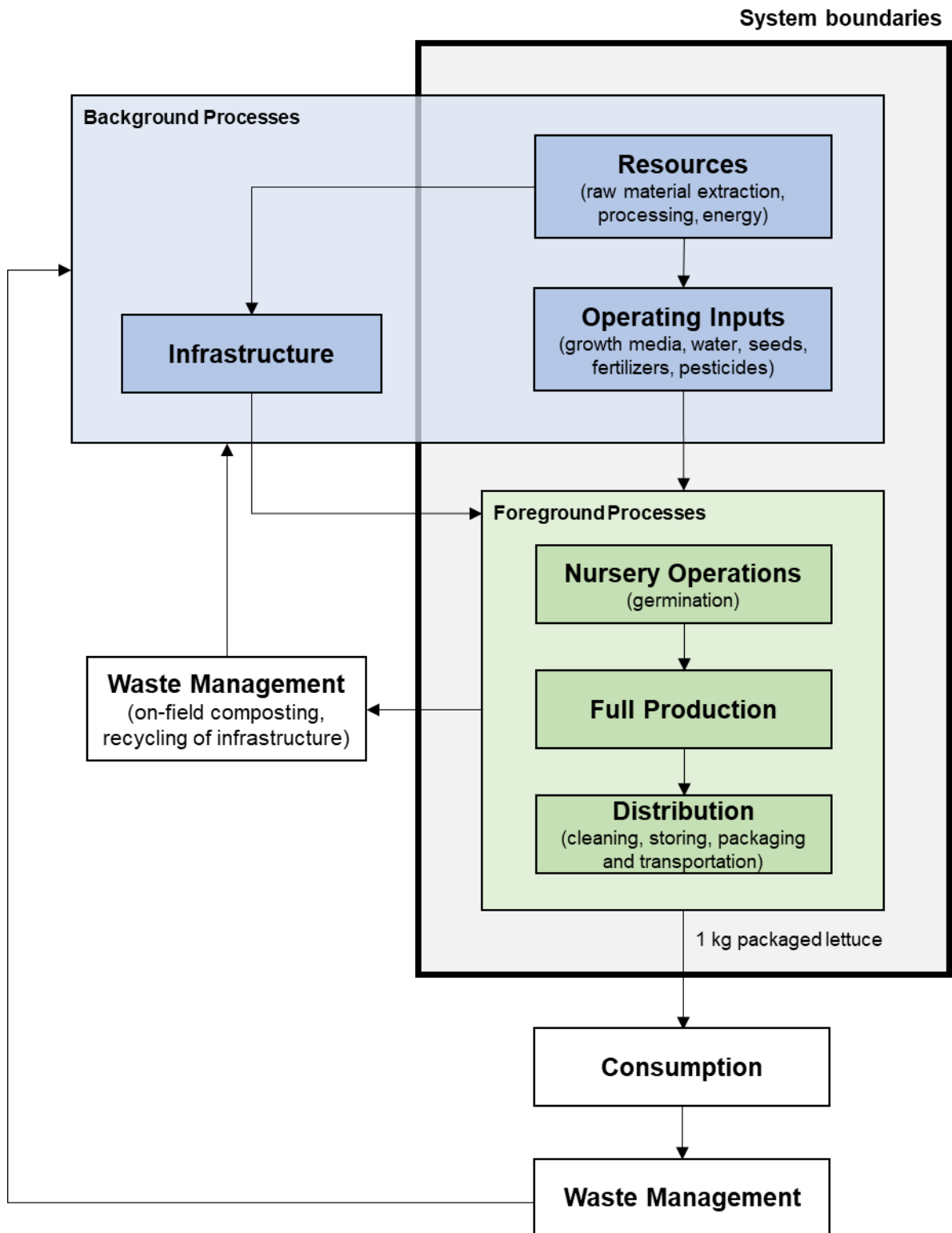


Figure 3-1. System Boundaries (adapted from Bartzas, Zaharaki, & Komnitsas, 2015; Dias et al., 2017)



### 3.3.2 MODELING CONVENTIONAL AND COMPACT LETTUCE PRODUCTION

Based on the system boundaries discussed in section 3.3.1 and illustrated in Figure 3-1, the conventional agriculture system and the compact agriculture system follow a similar process. However, the two systems differ in three aspects. First is their use of infrastructure to produce lettuce. Conventional farming uses agricultural field and machinery such as tractors, ploughs, and harvesters. On the other hand, compact agriculture uses an indoor shipping container (considered for this study) and hi-tech equipment such as hydroponic system, LED lights, HVAC, ventilation system, and fertigation system to control the growth environment. Though infrastructure is not included within the system boundaries it dictates the consumption of operating inputs. Second is the use of pest control methods. Since compact agriculture system has a highly controlled environment it does not employ pest control techniques, whereas conventional agriculture system uses both chemical based pesticides and herbicides. Third is the storage of produce before distribution. Conventional agriculture requires storage of lettuce since it produces in fairly large quantities, while compact agriculture does not as it is assumed to be a demand-driven production facility.

#### 3.3.2.1 Assumptions

This study tried to keep some of the processes within the two systems as similar as possible for simplification purposes. For instance, nursery and packaging operations were assumed to be on-site and use the same materials in both the systems. Packaging material consumption per FU was estimated based on standard practice of lettuce packaging (*For keeping Romaine and Iceberg Lettuce their freshest*, n.d.). One corrugated cardboard box weighing approximately 1.61 kg with a holding capacity of 25 kg was assumed to be used. In addition, standard sealing tape was used to pack these boxes.

However, location of production sites was considered to be different to capture the food mile aspect. Compact agricultural system was assumed to be located in the City of Toronto whereas, conventional agricultural system was assumed to be located in Yuma,

Arizona in USA. This was based on the fact that Yuma, Arizona is the largest producer of lettuce in USA and USA is the largest exporter of lettuce to Canada (Agriculture and Agri-food Canada, 2014).

### 3.3.2.2 Conventional lettuce production

Conventional agriculture is defined as “the practice of growing crops in soil, in the open air, with irrigation, and the active application of nutrients, pesticides, and herbicides” (Barbosa et al., 2015). Figure 3-2 depicts a typical conventional farm producing romaine lettuce.



Figure 3-2. Conventional farm producing lettuce (Pigott & Communications, n.d.)

Ecoinvent v3.3 database was utilized for production of lettuce through conventional system. The available dataset is based on a study by Stoessel, Juraske, Pfister, & Hellweg (2012) where the inputs and outputs had been extrapolated for the year 2016. The inventory is based on lettuce production in Switzerland which is well representative for productions in industrialized countries or farms which produce similarly such as in the USA.

The dataset covers seedling production to harvest and storage of lettuce. The yield for production of lettuce on a conventional farm is estimated at 26 tonnes per hectare with a cropping cycle of 2.25 months. The greenhouse heating energy for seedling production and electricity for a storage period of 0.3 months is included. Pesticide inputs are classified according to their chemical classes and the emissions are assigned to the soil (100%). Mercury emissions are neglected due to lack of data. The dataset does not include infrastructure used for production and storage facilities. No transports for agricultural means of production are included. Fertilizing by broadcaster is used as a proxy for all the machinery work done in horticultural processes. Table 3-1 illustrates the inputs required for 1 kg of packaged lettuce by conventional agriculture at the farm gate.

Table 3-1. Operational inputs for 1 kg of conventional lettuce at farm gate

<b>Fertilizers</b>		
Ammonium nitrate, as N	0.00372	kg
Phosphate fertilizer, as P <sub>2</sub> O <sub>5</sub>	0.00070	kg
Potassium sulphate, as K <sub>2</sub> O	0.00519	kg
<b>Pesticides</b>		
Diazole-compound (pesticide)	3.87000E-5	kg
<b>Water</b>		
Irrigation water consumption	0.02320	m <sup>3</sup>
Tap water, at user/CH U (water for washing)	0.40000	kg
<b>Energy</b>		
Heat, central or small-scale, other than natural gas (seedling production)	0.17700	MJ
Electricity, low voltage (storage before distribution)	0.01500	kWh

It was assumed that a refrigerated truck is required to transport lettuce for such a distance in order to preserve its freshness for as long as possible. The road distance between Yuma, Arizona and Toronto, Ontario was calculated using google maps tool and estimated to be about 3,855 km. For this purpose, a freight lorry with a refrigeration machine and a 7.5-16-ton capacity was considered. It was also estimated that 15% of the lettuce is

lost before reaching the retail gate (Economic Research Service (ERS) & U.S. Department of Agriculture (USDA), n.d.; Strid & Eriksson, n.d.).

### 3.3.2.3 Compact lettuce production

Primary module from Modular Farms Co was considered as the archetype for this purpose (Figure 3-3). The primary module is a purpose-built container measuring 40 feet long, 10 feet 5 inches wide, and 10 feet 11 inches tall (Modular Farms Co, n.d.). It houses 240 eight feet ZipGrow growing towers with over 3,800 plant sites, 72 119W Philips Greenpower LEDs with automated day/night schedule, an HVAC system for cooling, a stainless steel multi-functional work table, a close-looped fertigation system, and seedling troughs (Modular Farms Co, n.d.). It also includes an automated farm system and a climate control system to govern light, temperature, humidity, CO<sub>2</sub>, and ventilation within the container. The module utilizes hydroponics through a nutrient control and delivery mechanism.

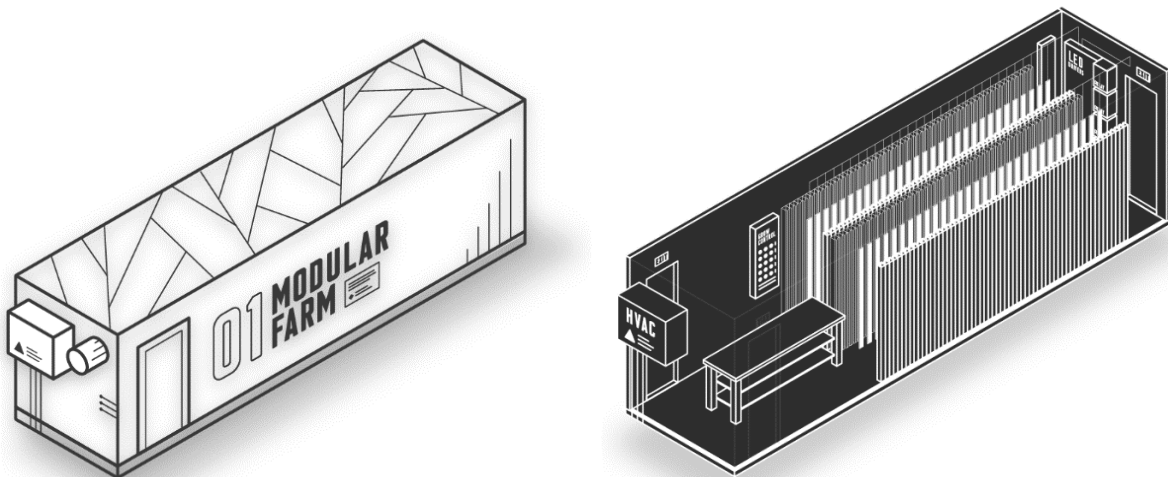


Figure 3-3. Primary module from Modular Farms Co (Modular Farms Co, n.d.)

The nursery (part of the multi-functional worktable) can seed about 3600 plants. This study assumed stone wool as the substrate used for lettuce germination. It was estimated that 48 stone wool cubes weigh about 200 grams. Once germinated, the seedlings are transplanted to the ZipGrow growing towers. A controlled environment within the container results in consistently uniform and productive crop yields. Estimations for production of lettuce through the compact shipping container system were based on information available on Modular Farms Co. and ZipGrow websites. Table 3-2 illustrates the inputs required for 1 kg of packaged lettuce by compact agriculture at the farm gate.

Table 3-2. Operational inputs to produce 1 kg of compact lettuce at farm gate

<b>Fertilizers</b>		
Ammonium nitrate, as N	0.00011	kg
Phosphate fertilizer, as P <sub>2</sub> O <sub>5</sub>	0.00020	kg
Potassium sulphate, as K <sub>2</sub> O	0.00048	kg
<b>Water</b>		
Irrigation water consumption	0.00230	m <sup>3</sup>
<b>Energy</b>		
Electricity, low voltage	16.19822	kWh

Lettuce is harvested by hand in the container and because of hygienic growing conditions it does not require washing. It is assumed that on-site packaging method similar to the one in conventional farming is used. Since the container farm is believed to be located within the City of Toronto and catering to the residents, transportation is via road. It was assumed that the compact farm will be located at Evergreen Brickworks in Toronto where a similar urban agriculture company has operations. The retail gate is assumed to be in Downtown Toronto which is 5 km away from Evergreen Brickworks and a light commercial vehicle with a load capacity of 0.7 ton is used for transporting lettuce for that distance. It is also estimated that there is a wastage of 5% in shipping container compact farm before the retail gate (Modular Farms Co, n.d.).

### 3.3.3 LIFE CYCLE INVENTORY AND IMPACT ASSESSMENT

The Ecoinvent 3.3 database was used to characterize background processes such as the production of energy, manufacture of operational inputs to the processes, and emissions and fuel consumption for modes of transportation. Software program, OpenLCA version 1.7.0 © GreenDelta 2018, was used for life cycle impact analysis of the two product systems. Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) 2.1 method was used for accounting and analysis of the emissions and midpoint level impacts. TRACI is an environmental impact assessment tool developed by the United States Environmental Protection Agency (US EPA) and is the only LCIA method based on North American characterization factors (Bare, 2011).

Further, considering the goals of the study, a subset of TRACI impact categories was chosen to reflect environmental impacts. Therefore, the impact assessment focussed on global warming potential, acidification potential, eutrophication potential, ozone depletion potential, and resource depletion – fossil fuel potential. These impact categories are described in Table 3-3.

Table 3-3. Description of impact categories in TRACI 2.1 used for impact assessment in this study (adapted from Bare, 2011)

Impact category	Description	Measurement
Global warming	Warming that can occur as a result of increased emissions of greenhouse gases from human activities	Carbon dioxide equivalent
Acidification	Increasing concentration of hydrogen ion (H <sup>+</sup> ) within a local environment	Sulphur dioxide equivalent
Eutrophication	Enrichment of an aquatic ecosystem with nutrients that accelerate biological productivity and an undesirable accumulation of algal biomass	Nitrogen equivalent
Ozone depletion	Reduction of the ozone layer in the stratosphere	Chlorofluorocarbons equivalent
Resource depletion – fossil fuel	Resource depletion by use of fossil fuels	Megajoule (MJ) surplus

Results of the two product systems were compared for the selected impact categories. Further, the relative indicator results of the two product systems were compared. For this, the maximum result was set to 100% for each impact category and the result of the other product system was displayed in relation to this maximum result.

The sensitivity of the results was further assessed. In a sensitivity analysis, various model inputs are considered individually, and the degree to which changing the value of those inputs has meaningful effects on the results is assessed (H. Scott, Chris T., & Deanna H., 2015). Two alternate impact assessment methods, Eco-indicator 99 (I) and ReCiPe midpoint (I) v1.11, which are European context-based impact assessment methods were taken for this analysis. Relative indicator results were used to assess the sensitivity as the units were different for each impact assessment method. The impact categories used from the two alternate impact assessment methods are noted in Table 3-4.

Table 3-4. Impact categories in alternate impact assessment methods used for sensitivity analysis

Impact assessment method	Impact categories used
Eco-indicator 99 (I)	Climate change, ecosystems quality – acidification and eutrophication, ozone depletion
ReCiPe midpoint (I) v1.11	Climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, ozone depletion, fossil depletion

This study also analysed the contribution of the different processes in the two product systems on the impact categories. This contribution analysis allowed to achieve the study’s goal of identifying the stage(s) in the life cycle for the two systems that contribute most towards environmental impact and thus suggesting possible improvement scenarios.

Further, a scenario analysis based on cleaner electricity production was conducted. The baseline scenario of compact agriculture which used an electricity grid mix of Ontario as per Ecoinvent 3.3 was replaced by electricity grid mix of Quebec and Manitoba as per

Ecoinvent 3.3. Ecoinvent data on electricity production is based on 2015 data by Statistics Canada and extrapolated to the year 2016. Additionally, a scenario representing electricity grid mix of Ontario in 2018 based on data provided by Statistics Canada and Independent Electricity System Operator (IESO) was also compared with the baseline scenario. The electricity grid mix of the baseline and alternate scenarios are provided in Table 3-5.

Table 3-5. Electricity grid mix scenarios used for scenario analysis

Electricity source	Ontario 2016	Ontario 2018	Quebec 2016	Manitoba 2016
Nuclear	50.99%	54.79%	NA	NA
Hydro	25.94%	23.26%	94.23%	95.64%
Combustible Fuels (natural gas - conventional power plant)	13.17%	8.23%	1.4e-3%	0.09%
Wind	2.98%	7.27%	3.59%	2.35%
Coal and lignite	2.24%	NA	NA	0.17%
Biofuel	0.74%	NA	0.74%	NA
Solar	0.39%	1.31%	NA	NA
Imports	3.55%	5.13%	1.43%	1.75%

## 3.4 RESULTS

### 3.4.1 ENVIRONMENTAL IMPACT OF COMPACT VS CONVENTIONAL AGRICULTURE

One of the objectives of this LCA study was to compare the environmental impact between compact and conventional agriculture. Table 3-6 summarizes Life Cycle Impact Assessment (LCIA) results of 1kg of packaged compact lettuce and 1kg of packaged conventional lettuce at retail gate in Toronto. For compact agriculture, the LCA results estimate global warming potential of 3.13 kg CO<sub>2</sub> eq and eutrophication potential of 0.00853 kg N eq per kg of packaged lettuce at retail gate. For conventional agriculture, the global warming potential of 1.39 kg CO<sub>2</sub> eq and eutrophication potential of 0.00326 kg N eq is estimated per kg of packaged lettuce at retail gate.



Table 3-6. LCIA results of 1 kg packaged compact lettuce and 1 kg packaged conventional lettuce at retail gate by TRACI v2.1 impact assessment method

Impact category	Compact Lettuce	Conventional Lettuce
Global warming potential (kg CO <sub>2</sub> eq)	3.13E+00	1.39E+00
Acidification potential (kg SO <sub>2</sub> eq)	1.09E-02	4.17E-03
Eutrophication potential (kg N eq)	8.53E-03	3.30E-03
Ozone depletion potential (kg CFC-11 eq)	3.23E-07	6.95E-07
Resource depletion – fossil fuels (MJ surplus)	4.34E+00	2.28E+00

Figure 3-4 illustrates the relative environmental impact of the two product systems based on the TRACI v2.1 impact assessment method. The five categories under study reveal a straight-forward result of higher environmental impact by compact agriculture production system. Four of the five categories: acidification; eutrophication; global warming; and resource depletion-fossil fuels have a higher impact potential by the compact agricultural system. The difference varies from 48% in case of resource depletion – fossil fuels to 62% in case of acidification potential (Figure 3-4). In contrast, ozone depletion has a higher impact potential by the conventional agricultural system with a difference of 53% between the two systems (Figure 3-4).

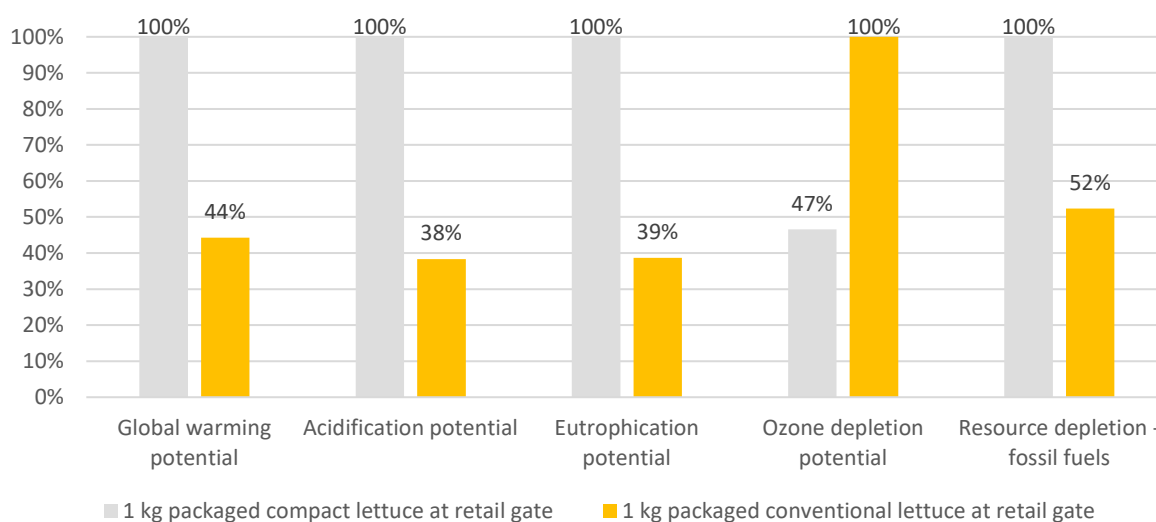


Figure 3-4. Relative indicator results of 1 kg packaged compact lettuce and 1 kg packaged conventional lettuce at retail gate using the TRACI v2.1 impact assessment method. For

each indicator, the maximum result is set to 100% and result of the other product system is displayed in relation to the maximum result.

### 3.4.2 SENSITIVITY ANALYSIS

To illustrate sensitivity of results above, an analysis with two alternate impact assessment methods, the Eco-indicator 99 (I) and ReCiPe midpoint (I) v1.11, was performed and compared. Figure 3-5 and Figure 3-6 illustrate the relative indicator results by the two additional impact assessment methods (see appendices for absolute figures). The sensitivity analysis with both Eco-indicator 99 (I) and ReCiPe midpoint (I) v1.11 show similar results to TRACI v2.1. Climate change (also global warming), acidification, eutrophication, and fossil depletion potentials are higher in case of compact agricultural system while ozone depletion potential is lower in case of compact agriculture in all three impact assessment methods. The relative variation in results is miniscule. ReCiPe midpoint (I) v1.11 impact assessment method, additionally illustrates lower impact potential of compact agriculture towards marine eutrophication.

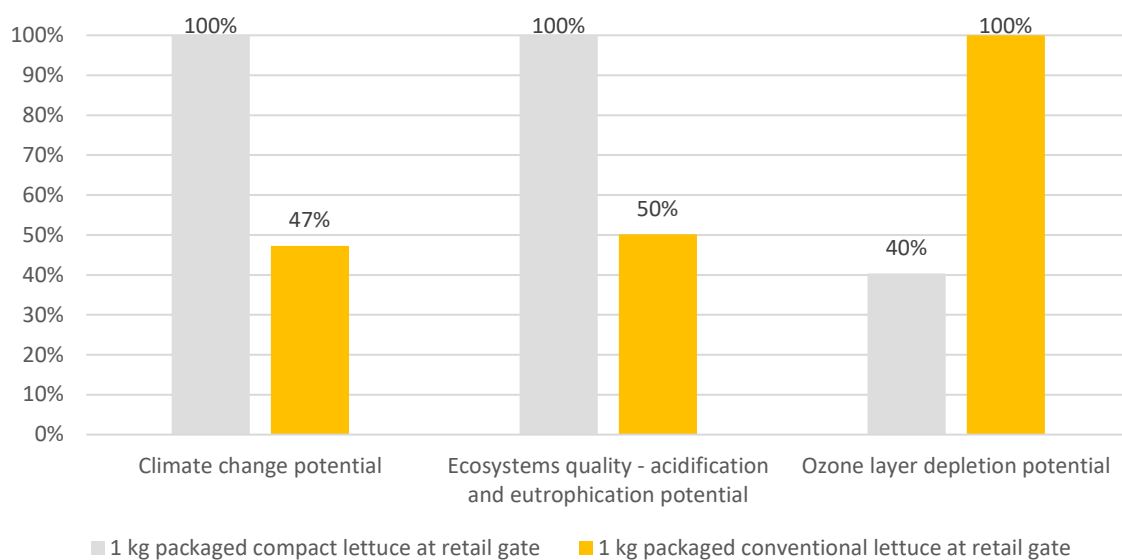


Figure 3-5. Relative indicator results of 1 kg packaged compact lettuce and 1 kg packaged conventional lettuce at retail gate using the Eco-indicator 99 (I) impact assessment method. For each indicator, the maximum result is set to 100% and result of the other product system is displayed in relation to this result.

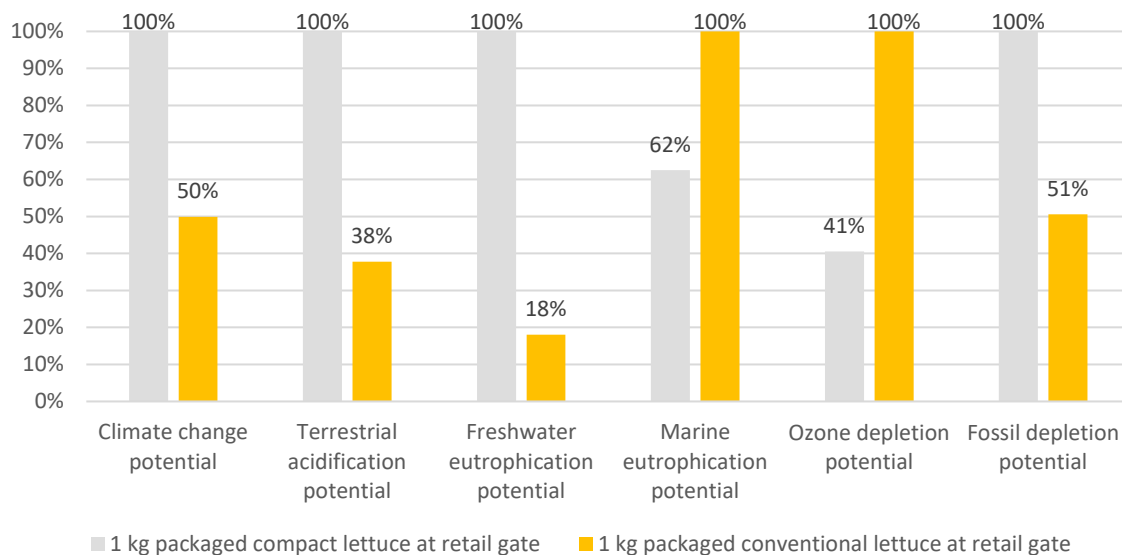


Figure 3-6. Relative indicator results of 1 kg packaged compact lettuce and 1 kg packaged conventional lettuce at retail gate using the ReCiPe midpoint (I) v1.11 impact assessment method. For each indicator, the maximum result is set to 100% and result of the other product system is displayed in relation to this result.

### 3.4.3 CONTRIBUTION ANALYSIS

The second objective of the study was to identify the stages in the life cycle of the two product systems that contribute most towards environmental impact. Figure 3-7 and Figure 3-8 illustrate process contributions in the life cycle of compact and conventional agriculture respectively. As discussed in other studies of closed environment agriculture systems (Benis, Reinhart, & Ferrão, 2017c; Goldstein et al., 2016a; Liaros, Botsis, & Xydis, 2016; Shiina, Hosokawa, Roy, Orikasa, et al., 2011), electricity is seen to be the highest contributor in case of such systems. For all five impact categories, electricity comprises more than 92% of the contribution in compact agriculture (Figure 3-7). Shiina et al. (2011), in their life cycle inventory of closed environment plant factory in Japan, discuss the high use of electricity for lighting and air-conditioning purposes in plant factories. However, due to unavailability of the distribution of electricity consumption amongst specific tasks (such as lighting, air-conditioning/ventilation, heating, etc.) it is difficult to provide an improvement case in terms of processes in the product system.

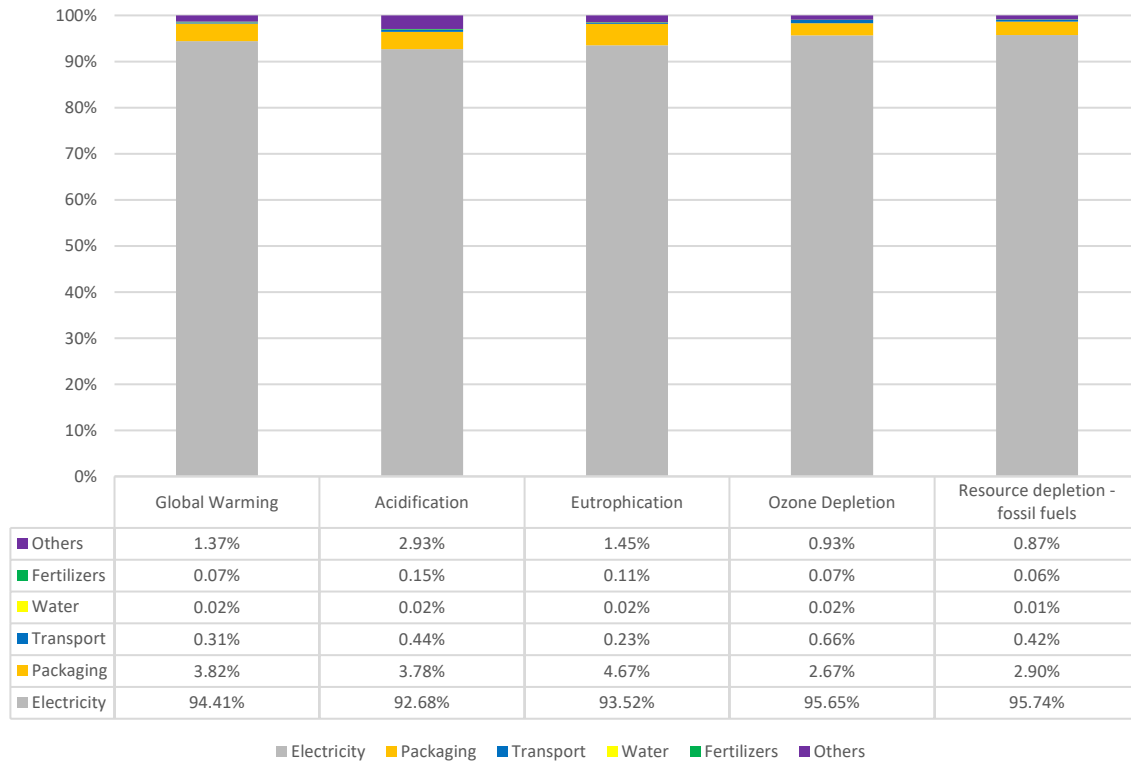


Figure 3-7. Contribution analysis of 1 kg of packaged compact lettuce at retail gate.

Transportation is the highest contributor towards the impact categories in case of conventional agricultural system (Figure 3-8). This is largely due to the assumption of lettuce being transported about 3,855 km from Yuma, Arizona to Toronto, Ontario by a refrigerated truck. In relation, lettuce coming from closer areas like Leamington, Ontario (OMAFRA, n.d.) is expected to travel much less distance and therefore have much lesser impact by transportation. This is also the reason why conventional agriculture has comparatively higher ozone depletion potential compared to compact agriculture though other processes such as electricity and/or heat have much higher overall impact. Interestingly, though fertilizers have a relatively high environmental impact in conventional agriculture, pesticides are very low contributors of environmental impact in conventional agriculture.

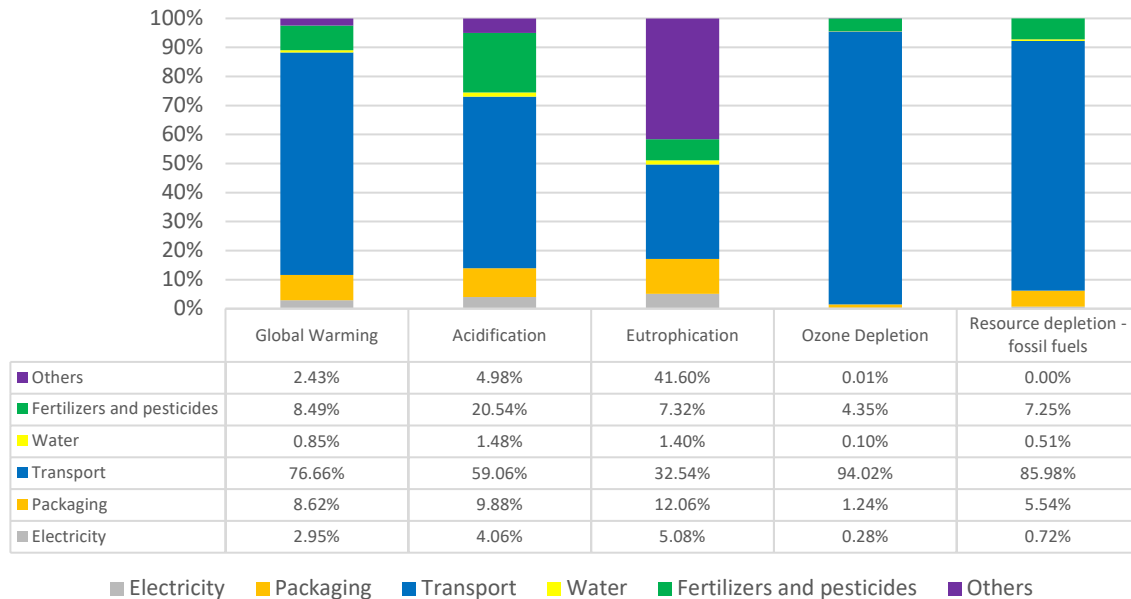


Figure 3-8. Contribution analysis of 1 kg of packaged conventional lettuce at retail gate.

Water has relatively low contribution in both compact as well as conventional agriculture. In case of compact agriculture, the fertigation system is highly efficient being a closed-loop system. On the other hand, in case of conventional agriculture, water consumption is mostly dependent on natural precipitation with marginal use of ground water for irrigation and washing purposes.

### 3.4.4 SCENARIO ANALYSIS – CLEANER ENERGY PRODUCTION

Contribution analysis for compact agriculture illustrates electrical energy as the highest contributor towards environmental impact. Furthermore, impact of different electricity production sources used in Ontario on the impact categories shows considerably high contribution of natural gas and oil towards global warming, acidification, ozone depletion, and resource depletion potential (Figure 3-9). This contrasts with only 13% of the electricity produced in Ontario by natural gas and oil (Table 3-5). In addition, the use of hard coal and lignite contributes considerable towards global warming, acidification, and eutrophication

potential with being only around 2% of the electricity mix (Figure 3-9 and Table 3-5).

Distribution/transmission network of electricity is another big contributor toward environmental impact particularly acidification and eutrophication potential (Figure 3-9).

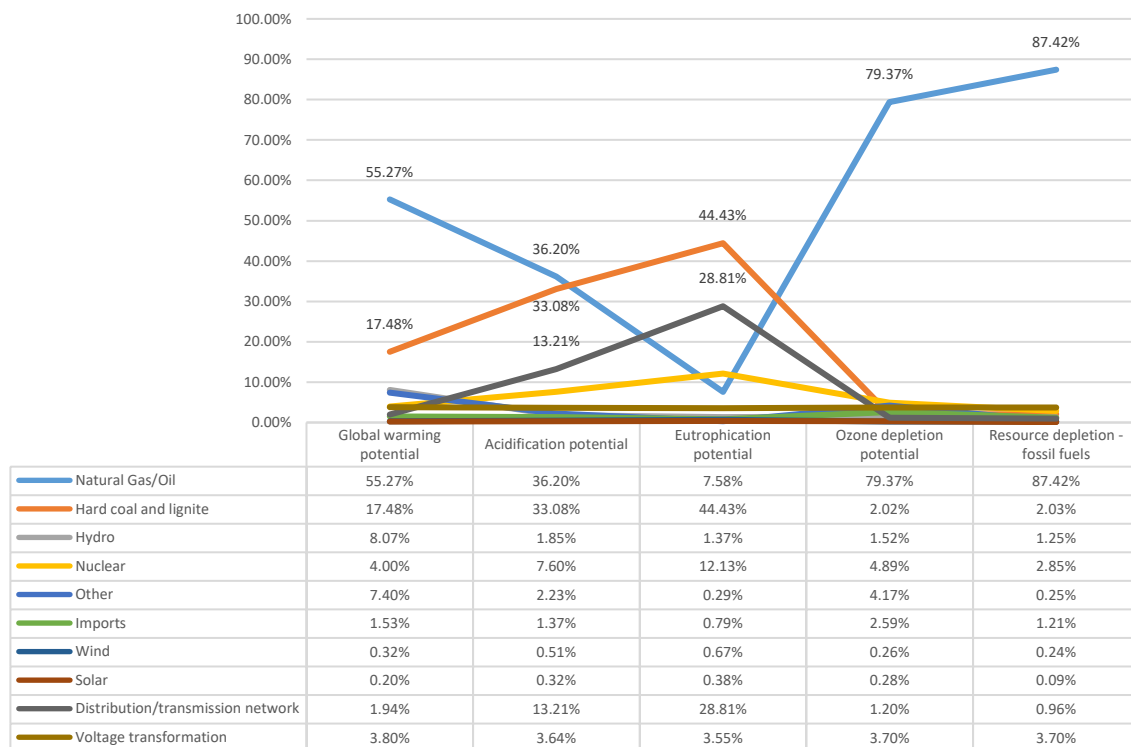


Figure 3-9. Contribution of different sources of electricity on impact categories.

Further, a scenario analysis based on cleaner electricity production illustrates drastic changes in environmental impact of compact agriculture. Figure 3-10 provides relative indicator results for three additional scenarios including Quebec’s electricity grid mix for 2016, Manitoba’s electricity grid mix for 2016, and Ontario’s electricity grid mix for 2018. The results show up to 44% drop in environmental impacts in case of Ontario’s 2018 grid mix. This is still higher than the impact by conventional agriculture. However, Quebec’s and Manitoba’s electricity grid mix are much cleaner than Ontario’s. This is reflected in the results where compact agriculture with Quebec grid scenario has lesser impact than conventional agriculture in all five impact categories. Compact agriculture with Manitoba grid scenario has comparable impacts to conventional agriculture for global warming and

acidification potential, lower impact for ozone depletion and resource depletion potential, and higher impact for eutrophication potential. The lesser impact in case of Quebec and Manitoba grid is attributable to the lower use of natural gas, oil, hard coal, and lignite as sources of electrical energy.

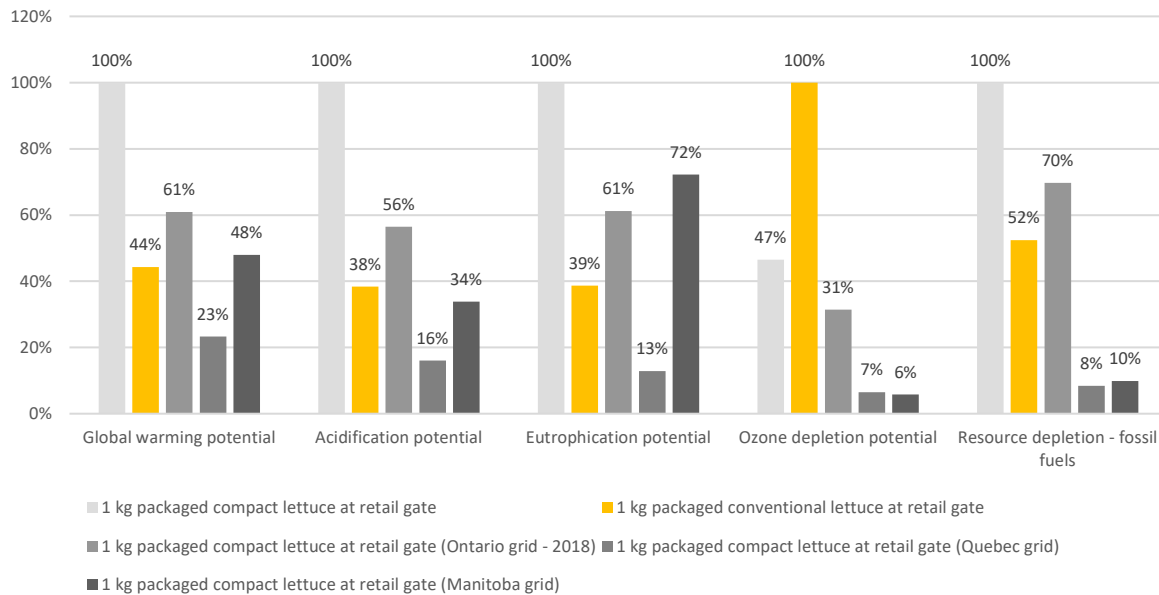


Figure 3-10. Relative indicator results of 1 kg packaged compact lettuce, 1 kg packaged conventional lettuce, 1 kg packaged compact lettuce with Ontario 2018 grid, 1 kg of packaged compact lettuce with Quebec grid, and 1 kg of packaged compact lettuce with Manitoba grid at retail gate using TRACI v2.1 impact assessment method. For each indicator, the maximum result is set to 100% and result of the other product system is displayed in relation to this result.

### 3.5 DISCUSSION

This study sought to evaluate which of the two product systems, compact or conventional agriculture, has the least environmental impact and if there are trade-offs; and identify the stage(s) in the life cycle for the two systems that contribute the most towards environmental impact and thus suggest possible improvement scenario(s). The following sections discuss key findings in the context of existing literature, describe strengths and limitations of this study, and provide recommendations for future research.

### 3.5.1 KEY FINDINGS

Life cycle thinking is often useful in making comparisons and in-turn decisions on whether one option is environmentally better than another or whether they are equal (Matthews, Hendrickson, & Matthews, n.d.). Since compact agriculture is a novel concept, it is important to understand its long-term environmental implications. Life cycle assessment of compact vs conventional agriculture carried out in this study can enable informed decisions to be made.

Three key findings emerged from this study. First, compact agriculture production for lettuce, at present, has a higher potential for environmental impact than conventional production for lettuce. Second, electricity consumption is the highest contributor towards environmental impact potential in compact agriculture. Third, compact agriculture can become more environmentally sustainable with shift to cleaner modes of energy production.

#### *3.5.1.1 Compact agriculture has high environmental impact at present*

Results in this study show that the environmental impact of compact lettuce is generally higher than conventional lettuce. This is true in case of baseline scenarios, where compact lettuce was grown in the City of Toronto and conventional lettuce came from Yuma, Arizona. Compact lettuce has a lower impact potential only on ozone depletion potential compared to conventional lettuce. However, it has higher impact on global warming, acidification, eutrophication, and resource depletion impact categories compared to conventional lettuce regardless of the impact assessment method (as discussed in section **Error! Reference source not found.**). From an overall perspective therefore, conventional agriculture is seen to be more environmentally sustainable.

Previous studies also point towards similar findings in their research (Benis, Reinhart, & Ferrão (2017), Burés (2013), Goldstein, Hauschild, Fernández, & Birkved (2016), Gruia (2011), Harbick & Albright (2016), He & Lee (2013), Kozai (2013) Nishizawa (2014), Shiina



et al. (2011), Specht et al. (2014), and Winiwarter, Leip, Tuomisto, & Haastrup (2014)). They illustrate high global warming potential and eutrophication potential for compact agricultural forms of lettuce production despite having different system boundaries, different locations, and using different impact assessment methods. For example, an LCA study by [Shiina et al. \(2011\)](#) estimated a global warming potential of 6.4 kg CO<sub>2</sub> eq per kg of lettuce for a perfectly controlled plant factory and 2.3 kg of CO<sub>2</sub> eq per kg for a hybrid plant factory using natural lighting. Similarly, an LCA study by Goldstein, Hauschild, Fernández, & Birkved (2016) estimated global warming potential of 8.65 kg CO<sub>2</sub> eq per kg of lettuce and marine eutrophication potential of 0.0038 kg N eq per kg of lettuce for a ground-based conditioned modular urban agriculture system. Whereas, global warming potential of 0.08 kg CO<sub>2</sub> eq per kg of lettuce and marine eutrophication potential of 0.00014 kg N eq per kg of lettuce was estimated for a ground-based non-conditioned urban agriculture system.

#### *3.5.1.2 Electricity consumption is a matter of concern for compact agriculture*

As discussed in other studies of closed environment agriculture systems (Benis et al., 2017c; Goldstein et al., 2016a; Liaros et al., 2016; Shiina, Hosokawa, Roy, Orikasa, et al., 2011), electricity is seen to be the highest contributor in case of such systems. For all five impact categories, electricity comprises more than 92% of the contribution in compact agriculture (Figure 3-7). This study also indicates that among different process stages electricity consumption is the highest contributor in the life cycle of compact lettuce. Furthermore, Shiina et al. (2011), in their life cycle inventory of closed environment plant factory in Japan, discuss the high use of electricity for lighting and air-conditioning purposes in plant factories. However, due to unavailability of the distribution of electricity consumption amongst specific tasks (such as lighting, air-conditioning/ventilation, heating, etc.) it was difficult to ascertain this. While transportation is the highest environmental impact contributor in case of conventional lettuce, lower food miles in case of compact agriculture do not offset the intensity of electrical consumption. Li, Li, & Yang (2016) present a similar finding in their study.

### *3.5.1.3 Move towards cleaner production of electrical energy can make compact agriculture more environmentally sustainable*

Since electricity consumption is the highest contributor towards environmental impact potential in compact agriculture, improving the way electricity is produced is imperative for its success. This study points to considerable reductions in environmental impact if electricity production is from cleaner sources. Reduction in use of natural gas, oil, hard coal, and lignite can make considerable impacts. Ontario still produces over 8% of its electricity through natural gas and oil (see Table 3-5). A reduction of around 7% in use of natural gas, oil, hard coal, and lignite in case of Ontario from 2016 to 2018 sees a reduction of 30% (resource depletion potential) to 44% (acidification potential) in environmental impact.

Literature lacks evidence regarding this. Study by Goldstein, Hauschild, Fernández, & Birkved (2016) illustrated reduction in GHG emissions by up to 500% when replacing the electricity grid to solar or wind power for a ground-based conditioned urban agriculture system. However, the GHG emissions were still higher than ground-based non-conditioned agriculture even after the reduction. It is to be noted that the results in this study were based on unit area of land use rather than weight of commodity produced and taking yields into consideration may provide different results. Benis, Reinhart, & Ferrão (2017) further contend in their comparative study of conventional, rooftop greenhouses, and shipping container farms that associating clean renewable sources of energy can mitigate environmental footprint of these systems. Further, it may be beneficial for in-situ renewable sources of energy such as integrated solar photovoltaic panels

### **3.6 STUDY LIMITATIONS**

This study had several limitations. The limitations discussed below need to be considered in addition to the assumptions made when interpreting the results of this study and when contemplating future research on the matter.

This study looked at only the environmental aspect of sustainability associated with compact and conventional agriculture. There may be intangible costs and benefits in terms of food security, food quality, and economic development as described in literature which have not been captured in this study. Comparison with greenhouse or other forms of urban agriculture located within the City of Toronto was not considered. The food mile aspect may have a similar level of impact on the environment for other forms of urban agriculture located within the City of Toronto. The study considered lettuce production only and results may be very different for other crops. Compact agriculture has been generalized based on results from a shipping container farm. Data for compact agriculture was based on online information available on the websites of Modular Farms Co. and ZipGrow Farms. The Canadian division of Modular Farms Co. has shut operations although the company continues to operate from Australia. Plant factories and vertical farms with higher yields may give different results.

Ecoinvent v3.3 database was used for background processes. However, it is to be noted that Ecoinvent v3.6 database was available at the time of study but was not accessible due to financial constraints. TRACI v2.1 which is based on North American context was used as the primary impact assessment method, but sensitivity analysis involved comparison with Eco-indicator 99 and ReCiPe v1.11 which are European context-based impact assessment methods.

### **3.7 CONCLUSIONS**

Considering the limitations of this study, there is scope for further research on this topic. First, there is a need for added comparison with greenhouse and other forms of urban (community and rooftop) agriculture. This is particularly important in case of cold climate countries like Canada where greenhouse agriculture has a stronghold. Second, including infrastructure and waste management within the system boundaries will enable a much more comprehensive study which may give different results all together. Third, footprint of containers should be considered while assessing impacts. Larger containers or plant factories should benefit from economies of scale and have lesser per unit environmental impact. Last, the scope of cleaner energy production should continuously be deliberated upon. Improvements in how electricity is produced can have a significant benefit with respect to compact agriculture and eventually on the environment.

This study can enable informed decisions to be made with respect to compact agriculture implementation in cities. For instance, decision makers can look at how much electricity is expected to be consumed for compact agriculture and where the product traditionally comes from. Decision to permit compact agriculture can make sense if it has lesser environmental impact per unit of the product. However, a comprehensive cost-benefit analysis that encompasses social and economic aspects is recommended to supplement LCA studies.

# CHAPTER 4: PERCEIVED BARRIERS AND FACILITATORS FOR COMPACT AGRICULTURE IN CANADA: AN EXPLORATION OF MULTI-SECTOR KEY INFORMANT PERSPECTIVES

Co-authored by Dr. Leia Minaker, who provided supervisory guidance (including contributions to concept and methods formulation), and edits to written content.

## 4.1 ABSTRACT

Compact agriculture, which is essentially a hi-tech, high-density, and high-yielding agricultural practice within a completely closed environment, is a relatively novel concept within the food production realm. There are existing knowledge gaps around implementing and sustaining compact agriculture as a relatively new form of urban agriculture. As such, there are many challenges with respect to implementation of compact agriculture in urban areas but also a possibility to generate successful scenarios. This study explored how different stakeholders perceive barriers and facilitators related to establishing and maintaining compact agriculture in urban areas in Canada. Qualitative interviews with key informants were undertaken to achieve the objective of this study. The study found that stakeholders believe compact agriculture to be poised for explosive growth in the coming years and create its own niche in order to sustain itself. However, it also illustrated that stakeholders perceive economic, regulatory, and operational barriers to currently outweigh the facilitators associated with compact agriculture. Further, the stakeholders had differing views towards environmental and socio-economic impact of compact agriculture.

*Keywords: Compact agriculture, shipping container farm, vertical farm, plant factory, Canada, barriers, facilitators*

## 4.2 INTRODUCTION

The modern food system has become highly industrialized (Ericksen, 2008; Kasper et al., 2017; Pothukuchi & Kaufman, 1999). Pothukuchi & Kaufman (2000, p.113) define the food system as “the chain of activities connecting food production, processing, distribution, consumption, and disposal as well as all the associated regulatory institutions and activities”. The current food system “has profound impacts on a host of different sectors” (Morgan, 2009, p.341) and is a major contributor towards global environmental deterioration (Springmann et al., 2018; Weidner et al., 2019). The environmental impacts of the food system are often associated with “climate change, land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems” (Springmann et al., 2018, p.519). A detailed review by Tukker & Jansen (2006) estimated twenty to thirty percent of the total environmental impact caused by humans to be attributable to food production (as cited in Hartmann & Siegrist, 2017). This in turn is likely to be about 80%-86% of the overall food system impact in terms of emissions (Vermeulen et al., 2012).

Research on food systems has historically been a rural affair (Born & Purcell, 2006). The requirement of large sized arable land for agriculture coupled with lack of adequate space in urban areas has had food production to remain a largely pastoral subject. However, rapid urbanization is changing the face of the global food system (Seto & Ramankutty, 2016). Over the next three decades, it is estimated that around 68% of the global population will be living in urban areas (*World Urbanization Prospects: The 2018 Revision*, 2018). An increase of about 2.5 billion people in the expanding urban areas will put tremendous pressure on the arable crop land and thus the food system (Seto & Ramankutty, 2016).

In the past couple of decades, there has been growing popularity of food system localization. Due to the growing concern over sustainability, agriculture is increasingly being considered in urban contexts. Many researchers have vouched for local food system to be a

sustainable alternative to the existing situation (Allen et al., 2003; Benis & Ferrão, 2018; Blay-Palmer et al., 2018; Crush & Frayne, 2011; Fraser et al., 2005; Hinrichs, 2003; Horst et al., 2017; Kasper et al., 2017; Lerner & Eakin, 2011; Morgan, 2013; Pothukuchi & Kaufman, 1999; Salvador, 2019). As such, discourse on urban agriculture has been gaining momentum (Chou, 2017; Despommier, 2010; Martellozzo et al., 2014). However, agriculture in urban areas has always been present in the global south and is reappearing in the global north (Huang & Drescher, 2015a; Morgan, 2009).

In North America, urban agriculture has roots in times of crisis. The United States government encouraged setting up of War Gardens and Victory Gardens during World War I and World War II respectively to increase food security and patriotism (Mok et al., 2014). Relief Gardens were promoted during the Great Depression of the 1930s in order to provide food, income and purpose to the unemployed (Bassett, 1981). The broader availability of food coupled with the consumerist lifestyles embraced after the war made backyard food production unnecessary. Interest in community and backyard gardens resurfaced in the late 1960s and early 1970s due to growing environmental awareness, counter-culture movement against consumerism, and economic uncertainty (Mok et al., 2014).

Urban agriculture is diverse in terms of its “scope, scale, type of access and for whom, participants, and goals” (Horst et al., 2017, p.280). Scholars have defined urban agriculture in many different ways but the most common conceptual building blocks of urban agriculture definitions are: types of economic activities; food/non-food categories and sub-categories of products; intra-urban and peri-urban character of location; types of areas where it is practiced; types of production systems; product destination; and production scale (Mougeot, 2000). One of the most widely accepted definitions was provided by Smit, Nasr, & Ratta (1996) which was eventually adopted by the United Nations Development Program (UNDP). They define urban agriculture as -

an industry that produces, processes, and markets food, largely in response to the daily demand of consumers within a town, city, or metropolis, on land and water

dispersed throughout urban and peri-urban areas. Typically urban agriculture applies intensive production methods, frequently using and reusing natural resources and urban wastes, to yield a diverse array of land-, water-, and air-based fauna and flora, contributing to the food security, health, livelihood, and environment of the individual, household, and community (p.1).

Conditioned or controlled-environment agriculture is a type of urban agriculture where the growth environment is regulated through the use of artificial lighting and ventilation as well as the use of soilless growing technologies (Besthorn, 2013; Nelkin & Caplow, 2008; Pfeiffer, Silva, & Colquhoun, 2015; Zeleny, 2012). Several names have been given to controlled-environment agriculture, including plant factories (Kozai, 2013; Takatsuji, 1987), building-integrated agriculture (Caplow, 2009), vertical farming (Bailey, 1915; Despommier, 2010), skyfarming (Germer et al., 2011), and zero-acreage or z-farming (Specht et al., 2014).

This study focuses on “compact agriculture”, which, according to the Association of Vertical Farming’s (AVF) urban agriculture integration typology, is an urban agricultural practice with completely closed exposure utilizing hydroponics, aquaponics, or aeroponics as growing medium for the purpose of sharing, preparing, retailing, or wholesaling for human consumption (Association for Vertical Farming, n.d.). Concepts like vertical farms, plant factories, and shipping container farms where the growth environment is human regulated are included within this concept, while concepts such as farming on walls and rooftops or in greenhouses and community gardens where the environment may only be partially controlled are excluded. Compact agriculture is anticipated to be hi-tech and to have high-density and high-yielding capabilities. The term ‘compact’ in compact agriculture is used to synchronize with the compact city concept. Efficient integration of urban agriculture within the compact urban form of cities to make them more self-sufficient, sustainable, and resilient is extremely important.

Efficient use of land and resources, reduced ecological and carbon footprint, reduced food miles, reduced building energy use, reduced wastage, improved biodiversity and soil



quality, increase year-round yields, improved air quality, protection from erratic weather conditions, and improved resiliency are some of the frequently mentioned advantages of compact agricultural forms (Goldstein et al., 2016b). One of the most frequently mentioned positive outcomes from implementation of these concepts in urban areas is food security for future generations in view of rising urban population and constraints on prime agricultural land (Caplow, 2009; Despommier, 2010; Germer et al., 2011; Specht et al., 2014).

However, several scholars disagree with the purported benefits of compact agriculture. They argue that the issue of food scarcity is more of a result of poverty and unequal distribution of food (Gordon & Richardson, 1997b). They further contend that urban agriculture does not solve equity issues and in fact causes exclusionary effects resulting in gentrification of urban areas (Guthman, 2003, as cited in Specht et al., 2014). Others contend that energy consumption and GHG emissions in controlled environment agriculture is much higher than in conventional agriculture. This is because the amount of electricity used towards provision of artificial lighting is much more than that is saved through reduction in food miles (Li et al., 2016).

Challenges for successful implementation of compact agriculture in cities include high investment costs, lack of public acceptance, availability of required technologies, zoning issues, maintenance issues, lack of experienced workers, and competition with economically attractive alternate land uses (Specht et al., 2014; Specht, Siebert, et al., 2016). Moreover, indoor farming is not suitable for all crops. For example, growing grains does not result in as much resource saving as growing vegetables and fruits does. It is also not viable to incorporate slow growing trees within indoor farms. Critics, therefore, believe that investments in other solutions may yield bigger returns.

The discussion on opportunities and challenges of the compact forms of agriculture in literature lacks strong empirical evidence in favor or against the claims that the proponents and critics make (Al-Chalabi, 2015). Though there may be challenges with respect to

implementation of compact agriculture, there is potential for generating successful scenarios in cities and therefore exploring realistic implementation strategies is a useful exercise.

Planning practice is important for sustaining urban agriculture in cities (Mendes et al., 2008; Thibert, 2012). Literature provides strategies for traditional forms of urban agriculture, however, implementing compact agricultural forms in cities is a new topic and thus missing from existing research. Some of the recommendations provided in case of urban agriculture, community gardens, and rooftop gardens can be adapted for compact agriculture in cities. The suggestions are primarily geared towards municipal policy level changes (Desjardins et al., 2011; Huang & Drescher, 2015b). Including urban agriculture in plans, policies, and by-laws is essential to remove legal barriers. Scholars also recommend to have explicit documentation of urban agriculture in plans and policies with preference of having its own land use designation (Mendes et al., 2008). In addition, comprehensive municipal food strategies can provide direction for the successful implementation of urban agriculture initiatives.

Despite the rising popularity and acceptance of urban agriculture (community and rooftop gardens in particular), the use of technologies such as hydroponics, aquaponics, and aeroponics has been infrequently mentioned in regulatory documents for food production in Canada. Policies and bylaws related to compact agriculture in the largest cities in five of the most populated English-speaking census metropolitan areas (CMAs) in Canada (Toronto, Vancouver, Calgary, Edmonton, and Winnipeg) demonstrate variability in terms of how Canadian cities treat compact agriculture. While cities like Vancouver, Calgary, and Edmonton regulate the provision of compact forms of agriculture in their respective jurisdictions, cities like Toronto and Winnipeg currently do not explicitly recognize these. Moreover, somewhat surprisingly, the City of Toronto allows for vertical agriculture in its official plan but does not define it in its official plan or zoning bylaws. These barriers can have negative impact on the development of compact agriculture businesses in the country.

Given existing knowledge gaps around implementing and sustaining compact agriculture as a relatively new form of urban agriculture, this paper explores how different stakeholders perceive barriers and facilitators related to establishing and maintaining compact agriculture in urban areas in Canada.

### **4.3 METHODS**

This study started with a constructivist research philosophy. A qualitative approach and grounded theory research design was used to answer the research question (Creswell, 2014; Miles & Huberman, 1994). Key informant' interviews was the principal method of data collection for this study. This study was reviewed by and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#40365).

The key informants were identified through a purposeful sampling technique. Huang & Drescher (2015) identify six key stakeholders in the field of urban agriculture (groups which are equally applicable to compact agriculture): citizens; government and public authorities; non-government organizations; municipal departments; academic and research institutions; and private businesses. The roles of stakeholder are further characterized into either of regulation, facilitation, provision, or partnership.

For this study, key informants were categorized under the following four categories: non-government organizations; municipal departments; academic and research institutions; and private businesses. Private businesses were further categorized into those operating compact agriculture farms and those providing consulting services to set up such farms. Citizens, government and public authorities were purposely not included in this research.

Further, a snowball sampling technique was used to identify additional participants. Nine interviews were conducted with a total of 10 participants, since one interview had two participants. One participant was categorized as both an academic and research institution

and a non-government organization representative. The number of final participants for each key informant category is illustrated in Table 4-1.

Table 4-1. Number of participants for each key informant category

Key informant category	Number of participants
Non-government organizations	1
Municipal departments	3
Academic and research institutions	3
Private businesses - compact agriculture operators	2
Private businesses - Consultants	2

All interviews were conducted over the telephone which lasted between 30 and 45 minutes. The interviews were organized as semi-structured interviews and an interview protocol (see Appendix C) was prepared to guide the interviews. Interview questions were based on the following categories: knowledge and position on the concept of compact agriculture; state and suitability of compact agriculture in Canadian urban areas including characteristics of cities that suit compact agriculture; comparison with other forms of agriculture; and insights into barriers and facilitators with respect to compact agriculture implementation in Canadian urban areas.

The interviews were audio recorded on two devices with permission from all key informants. All the interviews were transcribed to facilitate thematic analysis. NVivo 12 Plus was used to code the transcribed interviews and organize the data into themes and sub-themes. First, overarching preliminary themes based on the structure of the interviews were assigned in order to describe the content of interviews. Second, the whole text of three interviews were coded based on the preliminary themes. Third, patterns in the themes across the three interviews were examined. Fourth, the researchers (GK and LMM) reviewed and came to consensus on the themes and sub-themes. Fifth, the rest of the interviews were coded based on the refined themes and sub-themes. Finally, the themes and sub-themes were reviewed and refined again. A coherent narrative of the results follows.

## 4.4 RESULTS

### 4.4.1 STATE OF COMPACT AGRICULTURE IN CANADA AND THE CITY OF TORONTO

This section synthesizes key informants' perspectives on the state of compact agriculture in Canada and the City of Toronto.

All the respondents believed the growth of compact agriculture in Canada has been slow, despite increasing interest in it. One business operator mentioned “when you look at the broader country, I think there’s maybe only a handful of facilities across the country”. A few respondents were also of the opinion that the growth has been particularly slow in Toronto. A non-government organization representative, comparing the growth in Toronto with other cities, said “not just the states (USA), even compared to Montreal or Vancouver which have had these farms and that hasn’t happened here.” Some respondents recognized past failures as a possible reason for this stunted growth. For instance, an academic noted that these failures “created a bit of a sour taste quite frankly in the marketplace because so many have failed”.

The respondents also recognized a growing interest and momentum of compact agriculture space in Canada and Toronto. City of Toronto officials mentioned that they have been getting lots of enquiries for starting compact agriculture facilities. A municipal representative gave an example of a large-scale project by University of Toronto and Centennial College which further illustrated the growing interest in the space. They mentioned,

Centennial is promoting a project out in the east end of Scarborough. They are integrating the whole idea where it becomes this state of the art facility where they will train students on how to, in collaboration, their engineering students would help in the mechanics of how the system is working, other students will know how its growing and how they can optimize the growing. It’s a whole very thought out project training people for future jobs.

A business operator mentioned, “it’s (compact agriculture) definitely on the investment radar and there is a lot of activity. And the more money that gets into the space

will only push it forward faster. I think it has started to move.” The City of Toronto representatives also recognized the fact that the official plan of Toronto allows for vertical agriculture in employment areas as an ancillary use. They also noted that although the zoning bylaw does not yet permit compact agriculture, the city is working towards these permissions.

#### 4.4.2 BARRIERS TO COMPACT AGRICULTURE

The key informants identified multiple barriers impeding development of compact agriculture in Canada. The barriers have been categorized into five groups as illustrated in Figure 4-1. Economic and regulatory issues are recognized as two main barriers to entry into the compact agricultural space. Environmental and socio-economic issues fuel the sustainability discourse while operational issues tend to make operating compact agriculture difficult. Table 4-2 summarizes the barriers under these themes. These barriers are discussed in more detail in subsequent sections.

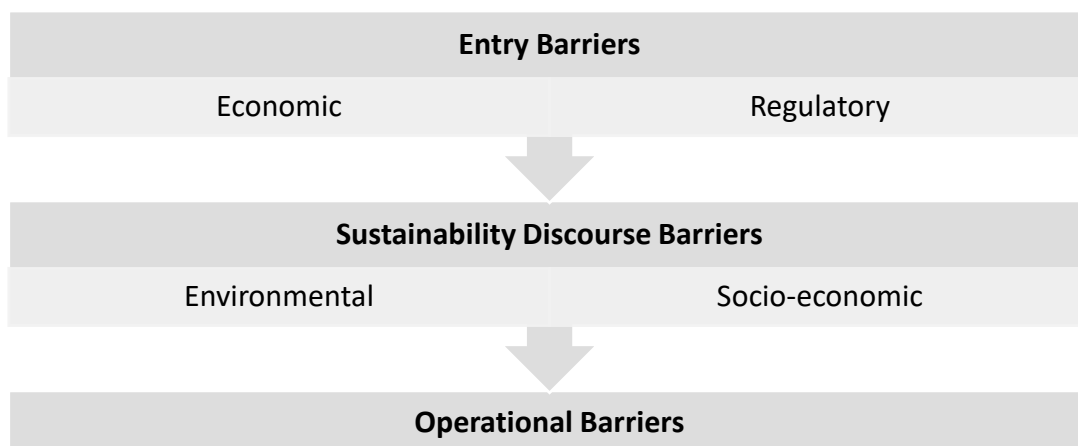


Figure 4-1. Barriers to compact agriculture

Table 4-2. Barriers for compact agriculture categorized into themes

Category	Sub-category	No. of interviews referenced	Key informant category represented
<b>Economic</b>	High cost of infrastructure	6	Business operator, consultant, academic
	High cost of real estate	3	Business operator, consultant, NGO
	Lack of capital and access to financial support	5	Business operator, consultant, municipal department, academic
	High operational costs	4	Business operator, consultant, academic
	Return on investment	8	All key informant categories
	<b>Total Economic</b>	<b>9</b>	
<b>Regulatory</b>	Political environment	4	Business operator, municipal department, NGO
	Policies	6	Business operator, consultant, municipal department, NGO
	Public acceptance	8	All key informant categories
	<b>Total Regulatory</b>	<b>6</b>	
<b>Environmental</b>	High consumption of energy	7	All key informant categories
	Waste generation and management	5	Business operator, consultant, academic
	<b>Total Environmental</b>	<b>8</b>	
<b>Socio-economic</b>	Impact on surroundings	3	Business operator, municipal department
	Employment	1	Municipal department
	<b>Total Socio-economic</b>	<b>3</b>	
<b>Operational</b>	Technology limitations	7	Business operator, consultant, municipal department, academic
	Limited production capacity	5	Business operator, consultant, academic, NGO
	Knowledge of growing	6	Business operator, consultant, academic, NGO
	Labour requirements	3	Consultant, academic
	Risk of contamination	2	Municipal department, academic
	Adhering to regulations	2	Consultant, academic
	<b>Total Operational</b>	<b>9</b>	

#### *4.4.2.1 Economic issues*

All respondents touched upon economic issues as one of the major barriers to compact agriculture growth in Canada. They highlighted high cost of infrastructure, high cost of real estate, lack of capital and access to financial support, high operational costs, and competition with other businesses as the main reasons for failure of compact agriculture businesses. These have been discussed further below.

##### High cost of infrastructure

The majority of respondents (six of the nine interviews) commented on the high cost of infrastructure used in compact agriculture as a barrier to entry. An academic stated, “they’re expensive systems to get started”. A consultant mentioned, “Cost has several elements to it also. Just general capital infrastructure cost is one”.

Some respondents referred to the approach of adapting technology as a barrier rather than the cost of technology itself. A business operator mentioned,

There were the early movers in the space that adapted the right approach, but the technology wasn’t mature yet in terms of the cost and efficiency. Then there was the approach where they tried too quickly to adapt high level of automation that made the whole capital expenditure upfront prohibitive and ultimately led to bankruptcy cause its only possible to sell the end product and it has a ceiling on how much you can actually charge if you are trying to recapture that initial investment.

They further suggested that it is,

An adaptation of taking a high-tech low-tech approach. So, trying to automate as efficiently as possible without over automating. So, kind of keep it simple kind of thing and try to make the facility as efficient as possible from a labour point of view and a resource point of view. And then that allows you to invest exorbitant amounts of money into the upfront costs of actually setting up these farms and actually create a business plan that can start to have an ROI (return on investment), something palpable to an investor, so 5 years or less basically.



## High cost of real estate

Three respondents referred to the cost of real estate in cities as a barrier. In addition to the general cost of real estate, a business operator also pointed towards the cost associated with zoning a property and bringing it up to the required food safety and health standards as prohibitive. They mentioned,

There are a lot of factories in Toronto right now that are empty. But again, they are zoned wrong, they are old, they are not up to the Health Canada code. So, if you have that investment to be able to make that better then you can do anything. A lot of the time that investment in making the building food safe and getting around the zoning will cost more than the technology that you need.

## Lack of capital and access to financial support

Five out of the nine interviews touched upon lack of capital and access to financial support as an issue, while three of these five interviews acknowledged funding and raising money for compact agriculture as issues in general. A municipal official stated that “there are a lot of people who want to get into this, but they don’t have the financial means”. They further mentioned that people interested in the compact agriculture business frequently expect the government to finance their endeavours. However, they also emphasized the fact that the government is not a lender and it does not get involved in something which lacks general economic benefits like job creation.

A couple of respondents acknowledged that subsidies given to traditional agriculture is a challenge for compact agriculture to compete economically. A business operator said, “I think there are a lot of incentives and a lot of subsidies around agriculture that are a challenge for the compact (agriculture) companies to navigate.” Further, an academic gave a good example of subsidizing imported produce an additional disadvantage for compact agriculture and it may be beneficial, particularly for northern communities, to have compact agriculture subsidized. They mentioned,

Currently, Canadian taxpayers subsidize the distribution of perishable produce to our cousins in the north to something in excess of a hundred million dollars a year. And we bring food, strawberries from Mexico and distribute them to northern Canadians. And even those subsidized commodities are still outrageously priced compared to southern Ontario kind of market cost, for example. So, under those conditions, the availability of local produce; it's still going to be expensive to grow strawberries in a snowbank in Yellowknife in a compact agriculture kind of application but I submit that the subsidy for the energy and the infrastructure to achieve that is better spent in the Canadian economy than it is in the Mexican economy.

#### High operational costs

Four respondents touched on the high cost of energy and labour as a barrier for operating compact agriculture. Energy cost is primarily driven by lighting required to replace sun as well as heating or cooling required to create that perfect growth environment for the plants. An academic said, "The cost of power makes the cost of product high. That's a barrier. And that's the main problem most people have."

Additionally, compact agriculture is seen as labour intensive despite the level of automation involved. The cost of labour to run and manage these are quite high to make these facilities viable. A business operator mentioned,

Vertical farms right now, especially in north America, is very labour intensive still even though people are talking a lot about automation. There are still a lot of people interfacing the workspace and that is a great limiting factor for making of compact agriculture production in a city centre viable.

#### Return on investment

The main argument with respect to economic feasibility of compact agriculture is its profitability, more specifically its return on investment compared to other prospects. Six of the nine interviews touched upon return on investment. Though profitability is important for the success of any business, respondents referred to return on investment as an indirect barrier due to its comparison with other business opportunities.

A consultant mentioned that “They are not exactly barriers of entry for that business, but they are just barriers that are indirect barriers - like should I do this, or should I do something else? When the conversation turns that way, it falls not so high in that option list.” They further stated that “compact farming is more expensive compared to the value it actually gives you, the expense to value or cost-benefit analysis doesn’t necessarily work out in its benefit.” Additionally, the non-government organization representative mentioned, “Whatever form of indoor agriculture, when you compare it to if you’re going to put in a hipster restaurant or whatever in such a space so the limitations, the costs of the space or its simply actual availability is certainly a limitation.”

The return on investment is also dictated by the choice of crops to be grown in compact agriculture and vice-versa. Growing staple crops, fruits, or flowers are resource intensive, which translates to more cost and impacts profitability of the facility. A municipal official mentioned that it is important pick and choose what you are going to grow, since “what products you can grow profitably and what products you can’t grow profitably” has a direct impact on return on investment.

#### *4.4.2.2 Regulatory issues*

Regulatory issues were one of the most critical issues identified with respect to barriers to compact agriculture. Respondents talked about the political environment, the policies around compact agriculture, and enforcement of policies as major barriers.

##### Political environment

The political environment was perceived as more supportive towards traditional agriculture due to large corporations involved and conducting business at national or international level. Several participants noted that anything that tries to compete with traditional agriculture quickly becomes a very political subject. A business operator mentioned,

If you start looking at and trying to compete against field agriculture, then it becomes very political. You are talking about government subsidies, transportation companies purchase order agreements between major corporations bringing stuff up from Mexico, etc. So, actually legitimately replacing that with something else I think becomes a larger topic than just understanding yes that it's a good idea as long as on the spreadsheet it makes financial sense.

A municipality official mentioned "I think right now, farmers don't look at it as any kind of threat. They look at it as more of a hobby than a business."

Another business operator said that politicians can be supportive in principle but fail to act. They stated,

In politics, they are always going to be like, 'Yeah, we support you, this is great', and then for them to act on something is very slow or there's always something that's more important ahead of you. So, they will say they support you or they want to support you and they will show up at your events. There's not much more than that they can really do.

#### Policies

Respondents discussed specific policy-related issues as barriers for compact agriculture. Zoning bylaws were one of the most critical barriers recognized by the respondents at present. Zoning was discussed more specific to Toronto rather than in general terms. Some respondents provided examples with regards to this issue. A business operator mentioned that they have faced zoning issues themselves in Toronto and stated that,

The City of Toronto itself is zoned in a bunch of different ways. I don't think anything is zoned for agriculture and the biggest fear right now is if they zone it for agriculture then people will come in and grow marijuana. Its something they are not really willing to change.

They further asserted that "To change zoning takes an insane amount of money and an insane amount of time. And that's one of the biggest issues that we have faced". Another business operator, giving an example of an affiliated company, suggested lack of knowledge among decision makers that makes the process to change zoning for compact agriculture time-consuming.

The City of Toronto is currently working on how to get the zoning bylaw to conform to and implement the new use of 'vertical agriculture' that has been permitted by the official plan specifically in employment areas. However, the development of policy or zoning is very slow paced. A municipality official stated,

I have had a lot of individuals who want to start compact farming in buildings and so on and then it comes down to they can't get the proper zoning to be able to do that. So, these are things we are working on internally to address. It may take a little while but it's slowly being addressed because it's a necessity. The city has to figure out how this can occur and yet also not infringe upon the population.

At present, the City of Toronto does not allow 'vertical agriculture' as its own principal use. It is only permitted as an ancillary use to a different principal use. A municipality official gave an example of how it can be permitted. They said,

I guess it depends on what part of the city or what zone it would be permitted in because right now we don't allow it as a standalone use under the building bylaw. So, in industrial zones you can have a food manufacturing use and as an ancillary use to that food manufacturing use you can have growing of food. If the main use is packing, freezing, canning, processing or manufacturing of food then you can have an ancillary growing operation.

Part of the issue is also the lack of explicit definitions in policy documents which makes implementation of compact agriculture subject to municipal officials' interpretation or understanding. The non-government organization representative said,

In policy and principle, it's (compact agriculture) welcoming but local community economic development officers and some of those may be supportive and some not. At the same time, there is only so much that the economic development can do when you have either the regulations that are discouraging or bylaws not explicitly saying that you are welcome. So, a lot of work needs to be done in this regard.

There are many things that people can do considering urban agriculture in general such as growing in their backyard. It does not matter which zone it is, and nothing prevents one from doing that. However, the issue of growing arises when people want to get into sales of produce or specific zones. The non-government organization representative mentioned that "It's not the act of growing something for your own consumption in many

places, generally you can do that more or less anywhere. It's more what you do with it and certain places that have more restrictions".

Another policy-related barrier for compact agriculture businesses is the risk of uncertainty associated with the process of getting approval to set up compact agriculture.

The non-government organization representative touched upon this fact and stated,

Those projects that have attempted to set those up have either managed to do it but after a difficult process or given up on it or moved to set it up elsewhere like in Mississauga rather than in Toronto. So, there has been quite a discouraging experience related to either the regulations, the process you have to go through to get approved or uncertainty built into the process. You go through it, you have to commit to going through it, find a lease and then apply and then if you're denied you're stuck with a lease where you cannot produce what you want to produce. That uncertainty means that you'll just say, 'I'm not going to take that risk' as opposed to saying this is what it will cost, you go through with it and you get approved in the end. Then you will do your cost benefit and you say, 'I'm willing to go through with this because I know what I'm getting at the end.' So, part of it is simply the uncertainty of the processes and the results of it.

The uncertainty in the process is exaggerated by the possibility of land use conflict, either of compact agriculture on surrounding land uses or surrounding land uses on compact agriculture. A municipality official explained that the Official Plan requires new sensitive uses to demonstrate that they can work well with other existing surrounding land uses and that they do not create an impact on those land uses because they were present first. This calls for various impact studies such as environmental impact assessment and traffic impact assessment which also adds to the cost of setting up compact agriculture.

#### Public acceptance

Consumer awareness and perception about indoor agriculture in general is a challenge. The majority of people have a lack of understanding and appreciation of where their food is coming from, and how it's certified. A business operator gave an example of their facility and said that even though they do not use any pesticides or harmful chemicals, the fact that they are not certified organic has caused problems with some consumers.

Consumer support for localized agriculture is proving to be a major point of acceptability for compact agriculture. The image of hydroponic growing is evolving, and the general overall acceptability of produce grown hydroponically is rising. Consumers' opposition and distrust towards the general agro-industrial economy is also fueling the growth of compact agriculture. Though consumers seem to be supportive of local produce and agriculture, it is too early to have a robust dataset around support on compact agriculture. The traditional mindset of relating agriculture with rural is an obstacle for compact agriculture. Culture appropriateness is another issue. As more of green leafy vegetables are grown in compact agriculture it is more suitable for cultures that accept that in their diets rather than cultures which have low acceptability for it.

Finally, one surprising factor that may influence public acceptability are potential allergic reactions due to the growing method. For example, a business operator raised the concern of how the use of fish in aquaponics can translate into the produce and affect customers who have a fish allergy.

#### *4.4.2.3 Environmental issues*

All respondents touched on the fact that environmental impact of compact agriculture at present times is a potential barrier for its implementation. They touched upon high consumption of energy and waste generation and management as potential sustainability concerns with respect to compact agriculture. These are discussed further below.

##### High consumption of energy

Seven of the nine interviews referred to higher levels of energy consumption in compact agriculture compared to field and greenhouse agriculture due to utilization of artificial lighting, ventilation, and heating or cooling systems. The potential negative impact on the environment is perceived as a barrier for compact agriculture from a sustainability perspective.

However, couple of respondents (a business operator and an academic) touched upon the fact that it is important to consider the overall energy footprint of compact agriculture when comparing with other forms of agriculture. They mentioned about the impact of distributing produce, different sources of energy used, and creating the hardware used in the facility. Few respondents thought that the overall footprint of compact agriculture is very high.

#### Waste generation and management

Waste generation and its management was another perceived barrier from sustainability perspective. Five of the nine interviews talked on this topic. They agreed that the waste (the inedible biomass) generated in compact agriculture can be immense and cause problems. This is because waste issues are either forgotten about or not carefully considered. An academic mentioned,

Those are issues that must be dealt with. Waste management is a critical aspect that is often forgotten by the initial proponents of growing a bunch of food in a box and they ended up with this big mountain of dead plant material at their back door because you forgot that you had to deal with that stuff.

Small scale farms have more problems dealing with waste in terms of managing waste in small facilities or having more waste generated because of the risk of not having sustained business commitments.

In addition to the dealing with solid waste, there are also issues handling wastewater in compact agriculture facilities which use hydroponics or aquaponics. The nutrient rich water needs to be recycled periodically. However, most of the times the water is dumped down the drain which exposes the sewage facilities to fertilizers, salt, and uncontrolled fish eggs or fish. Waste management issues also brings up contamination issues which is one thing compact agriculture is supposed to help reduce.



#### *4.4.2.4 Socio-economic issues*

Only three interviews (municipal department officials and a business operator) acknowledged socio-economic issues as barriers for compact agriculture. The probable impact on surroundings and employment were the two main issues talked about.

##### Impact on surroundings

Respondents talked about the possible impact of compact agriculture on its surroundings. They raised concern on lack of knowledge of the long-term impacts of compact agriculture on the built environment. Light pollution and traffic impact on the surroundings were the two main issues discussed with respect to compact agriculture. However, it should be noted that the impact depends on the design of compact agriculture and if compact agriculture is completely enclosed there would essentially be no light pollution.

##### Employment

In terms of employment generation in cities, compact agriculture was considered to have limited employment opportunities in comparison to traditional agriculture. A municipal official stated, "To my understanding, you know, per yield there is less individuals involved."

#### *4.4.2.5 Operational issues*

Operational barriers were also recognized by all respondents. They talked about technology limitations, production capacity, knowledge of growing, labour requirements, risk of contamination and adhering to regulations issues that can impact compact agriculture operations.

## Technology limitations

Four of the seven respondents that talked about technology as an operational issue, acknowledged the fact that the required technology such as LED lighting, HVAC, and other mechanical systems to control the growth environment is available and quite mature now. They further added that the technology is developing further in terms of overall efficiency and embracing higher level crops. However, they mentioned that adapting the right approach to technology, specifically automation, is an obstacle for success of compact agriculture.

An academic mentioned about present technological limitations. They said that with the current level of technology, the production in compact agriculture is constrained to green leafy vegetables like lettuce and microgreens. Furthermore, they asserted that the sensor technology at present confines the system to be in small rather than large spaces and also makes it difficult to recycle the hydroponic nutrient solution. A business operator mentioned that the next technology evolution is in the data and artificial intelligence side of things which will be beneficial for compact agriculture.

## Production capacity

Though compact agriculture is efficient, the production capacity of compact agriculture is limited. Many variables dictate production capacity, but it is predominantly due to the space, infrastructure, technology and capital cost requirements. The small scale of compact agriculture makes it difficult to compete with traditional agriculture. A consultant mentioned,

I think in some ways it's a capital cost question. So, if you build a large facility then you can sell to wholesalers and be of that benefit. In that case you get large contracts and once it's running smoothly you should be able to have low amount of waste and a strong relationship to supply the product efficiently to rest of the customers with high volume in it. But the majority of indoor farms and compact farms, they are small scale entrepreneurs and so they are not able to build large facilities which means they end up selling direct to consumers or restaurants. In some cases, they are run properly but in most cases those farms tend to have a lot of waste because restaurants change

their minds, consumers fall through, they overproduce or underproduce and that creates problems.

Also, there is a need to have the right production capacity to easily and effectively manage a facility. Another consultant stated,

Its just about tapping into it and using it in the right scale that makes sense. If you're starting to produce something like one or two tons of micro greens a day in the middle of Downtown Toronto, that's kind of pushing it. But if you're ... doing 20-70 kilogram of micro greens or lettuce a day, then you definitely can cater to a lot of outlets- you have co-op kitchens, small culinary restaurants which are again a niche market.

Knowledge of growing

Six of the nine interviews raised concerns on the overall knowledge of growing produce. They talked about the need to educate and the need for people to learn how to grow efficiently. A business consultant, referring to the workshops they hold said, "the first thing we ask students is has anybody ever thought of being a farmer and all of them say no". The non-government organization representative mentioned,

They are going to need to know how to do it. They have to learn to do it. They can easily fail but the willingness to learn is there among many, I think. It's just that acquiring it is a process. But that's with anything. If you are going to work in a kitchen of a restaurant, you have to learn and know what you're doing the same way.

Apart from the knowledge of growing, people running the businesses do not know or appreciate the limitations of the technologies that they use. An academic stated,

The vast variety of different technologies specially lighting and HVAC, the mechanical systems deployed to manage environment control requirements here, they're adequate but the proponents aren't skilled enough or experienced enough to appreciate the limitations of mechanical, electrical and lighting systems that they're attempting to deploy and so, that works for a bit but then it fizzles and dies.

Another academic mentioned that the knowledge can be enhance with more research and the lack of research in this domain is right now a barrier to the growth of compact agriculture.

## Labour requirements

Compact agriculture is still a very labour-intensive production system and the access to the required skill set of people is limited. Academics and one consultant touched upon labour requirements in compact agriculture. They mentioned that contrary to other forms of agriculture, compact agriculture calls for more skilled and technology-oriented workers who can deal with the sophisticated technologies that are deployed in the facilities. An academic stated,

The unique labor requirements is not just a normal farmer anymore, it's not gumboots and a garden hose, it's somebody who's technically savvy and has some appreciation for the maintenance requirement for computer automated environment control and the sensor technology that sustains it; that has to be reliable and robust.

## Risk of contamination

The risk of contamination in food is a huge issue and difficult to recover from. An academic stated "Lack of hygiene is what I've seen. I mean we've lost. And this is a greenhouse and south of Guelph. There was a microgreen business and it was huge and then they had an outbreak and then they went out of business. So, it's hard to recover from such a thing." They further mentioned that the contamination can occur from people accessing the facility or the nutrient solution being contaminated. A municipality official added that surrounding industrial uses that emit chemicals can also impact food.

## Adhering to requirements

There has been a lack of attention in following food handling and waste management guidelines in compact agriculture. This can certainly change over time with rise in popularity and become more of a barrier than it is now. An academic stated,

Waste management is probably big because they are going to be dumping nutrients down drains. I don't think anyone notices that. I've also seen that happen in growers and they just go in drains. And no one's watching. And that's a big problem with greenhouses as well and they are under a lot of pressure to reduce that. And I don't

think there's any pressure right now (for compact agriculture). So, its going to be an issue. At the moment, I don't think it is because no one's paying attention.

There are certain documentation and/or certification requirements to get produce into some grocery stores. This is again a barrier for compact agriculture. A business operator mentioned, "It is a little bit difficult to get into certain companies. Zehrs, Sobeys and all of those grocery stores, they are going to need a lot of documentation and Health Canada stuff and Canada GAP certification and that's all money based again."

#### 4.4.3 FACILITATORS AND OPPORTUNITIES FOR COMPACT AGRICULTURE

Respondents also talked about facilitators and opportunities to make compact agriculture work in Canada. These have been categorized into the five groups identified as barriers to compact agriculture in section 4.4.2. Table 4-3 summarizes the facilitators and opportunities under these themes. The facilitators and opportunities have been further discussed in more detail.

Table 4-3. Facilitators and opportunities for compact agriculture categorized into themes

Category	Sub-category	No. of interviews referenced	Key informant category referenced
<b>Economic</b>	Cost sharing	3	Consultant, academic, NGO
	Growing interest to invest	1	Business operator
	<b>Total Economic</b>	<b>4</b>	
<b>Regulatory</b>	Growing institutional support	6	All key informant categories
	<b>Total Regulatory</b>	<b>6</b>	
<b>Environmental</b>	Resource efficiency	5	Business operator, academic, municipal department, NGO
	Reduced food miles	4	Business operator, consultant, academic, municipal department
	Reduced land impacts	5	Consultant, academic, municipal department
	<b>Total Environmental</b>	<b>8</b>	

<b>Socio-economic</b>	Improved food security	8	Business operator, consultant, academic, municipal department
	Economic benefit	7	Business operator, consultant, academic, municipal department
	<b>Total Socio-economic</b>	<b>8</b>	
<b>Operational</b>	Knowledge sharing	4	Business operator, consultant, municipal department, NGO
	Marketing strategies	3	Business operator, academic, NGO
	<b>Total Operational</b>	<b>6</b>	

#### 4.4.3.1 Economic facilitators

Four respondents touched upon economic facilitators. They talked about how sharing of costs and the growing interest in investing in compact agriculture can accelerate the development of compact agriculture businesses.

##### Sharing of costs

Operational cost distribution can result in compact agriculture becoming economically feasible in the long run. An academic suggested the possibility of integrating compact agriculture in housing developments where the cost of production is included in the rent or maintenance cost. A non-profit organization representative and a consultant, on the other hand, suggested the use of existing networking systems and co-operatives to share the costs of production.

##### Growing interest to invest

Though there is lack of financial support for compact agriculture as discussed under section 4.4.2.1, compact agriculture has been gaining attention from venture capital firms. A business operator stated,

Venture capital firms in Toronto on Bay Street are looking at this and they have groups that are just dedicated to exploring vertical farming and compact options. So, it's definitely on the investment radar and there is a lot of activity and the more money that gets into the space will only push it forward faster.

#### *4.4.3.2 Regulatory facilitators*

Six respondents talked about growing institutional support as a facilitator under regulatory environment for compact agriculture.

##### Growing institutional support

More agrarian cities may have more assistance for compact agriculture in terms of available funding for agriculture. A consultant mentioned that major cities across the world are open to bringing food production closer to or within their city as it adds more value to their city. They further mentioned that the City of Toronto is very open to welcoming new technologies and that they received assistance from the City of Toronto in setting up an aquaponics system at a community centre. However, they added that it is important to adhere to the necessary requirements by the City to get their support. The consultant expressed the willingness of community centres to give up space to integrate vertical farming in form of edible landscapes and even supermarkets to allow businesses to use their parking spaces to do something like container farming.

#### *4.4.3.3 Environmental benefits*

Eight interviews identified improved resource efficiency, reduced food miles, and reduced land impacts as possible outcomes associated with compact agriculture. These are discussed below.

##### Improved resource efficiency

Five of the nine interviews touched on compact agriculture's potential to be highly resource efficient and consequently having lower environmental impact. This is primarily due to its high yielding capabilities compared to other forms of agriculture.

Compact agriculture can be particularly efficient in use of water due to the control of irrigation techniques utilized and the possibility of recycling water. The efficiency, however, can vary the type of technology used like hydroponics, aquaponics, or aeroponics. A business operator mentioned that with hydroponics, one can possibly use as much water as in traditional farming whereas with aquaponics and aeroponics the use of water can be significantly less compared to traditional farming. A non-government organization representative further added that the advantage of water efficiency is not exclusive to compact agriculture. Environment consciousness is getting people to use water more efficiently in other forms of urban agriculture and greenhouse agriculture.

In addition to water efficiency, one respondent also acknowledged the fact that compact agriculture can reduce pesticide use. This is due to the growth environment being controlled and regulated very diligently.

#### Reduced food miles

Four interviews touched on the food mile aspect related to compact agriculture. An academic stated, "If you just get down to the basics of it the closer you are to your food source, the less the carbon footprint, the lower the transportation cost, the less the environmental impact is, provided you have no issue distributing it." The ability to locate compact agriculture closer to the consumers in urban areas is an advantage. It reduces the need of transporting food from far away and translates to reduction in food miles as well as associated emissions and food waste.

One respondent (a business operator), however, discarded the food mile story that contends compact agriculture can offset the environmental impact caused while transporting food. They stated "I don't believe the food mile story that it offsets anything with the carbon footprint of a vertical farm. The energy is just too immense even if that comes from a renewable source or not."



## Land impact

The need for housing and expansion in cities has resulted in the use of prime agricultural land for non-agricultural uses. 5 interviews touched on the fact that compact agriculture can have a positive land use impact. Repurposing unproductive urban spaces like parking lots, abandoned warehouses, abandoned factories, abandoned shopping malls etc. to grow food can help free up agricultural land for food that is difficult to grow in compact agriculture. Though agricultural land availability can be a major challenge in a lot of locations, it is less of a challenge in Canada because of abundance of the available land mass.

### *4.4.3.4 Socio-economic benefits*

Respondents talked about food security and economic opportunities as the socio-economic benefits associated with compact agriculture in cities.

## Improved food security

Eight of the nine interviews discussed the food security aspect. Respondents covered topics of food safety, local food availability, and nutritional value through use of compact agriculture. All eight respondents agreed that compact agriculture can have a positive impact on food security.

The possibility of monitoring food production at a much greater level ensures provision of safe and uncontaminated food. The food safety aspect is a value add which can help create a niche for compact agriculture in the market. An academic stated,

I think the big boon that compact agriculture can bring to some elements of the agriculture sector is the food safety aspect. I think it provides the opportunity to be much more reliable in providing safe, uncontaminated food. That's a bonus that they haven't really talked about too much yet, but they will.

Since compact agriculture can be located virtually anywhere, it also has the potential to have a positive impact in terms of local food availability. Producing food within cities can help stabilize the food supply chain and improve resiliency for the cities while reducing the need to get food from other areas. This is also true for other forms of urban agriculture. However, considering the recent climate change dialogue and increase in extreme weather events, compact agriculture is an essential form of urban agriculture which can mitigate the risk of food insecurity in cities. Weather is not an issue for compact agriculture unless the city is susceptible to disasters. It provides an opportunity to serve in locations with extreme weather conditions. One respondent stated, “compact agriculture is essentially the only way to handle the challenge of delivering perishable produce to those parts (northern communities) of Canada.” A business operator mentioned that the city of Toronto only has a limited number of days worth of food for its population in case of an environmental disaster. They further stated that local food availability can improve food security for the city.

The respondents had differing opinions on nutrition and taste of produce grown in compact agriculture compared to traditional agriculture. Some respondents argued that there is no difference nutritionally while others stated that because compact agriculture is closer to the consumer it is more nutritious. One business operator mentioned,

So, whenever something is closer to you, it's going to be much more nutritious. That's just the way it grows. Because you are allowing the plant to create all the nutrients it needs and actually prepare itself the way it is supposed to. Whereas if you harvest it too soon and it has to kind of ripen on a truck somewhere, it doesn't work properly. It's not the way it is meant to be. So, it's going to be more nutritious if it's closer to you.

Depending on the growing technique used, produce from a compact farm can be fresher compared to traditional agriculture. A consultant stated,

In terms of food purity, simply because you can control freshness, you don't have to do things like ripen with chemical treatment or something like that for vegetables or you don't have to use some preservatives like liquid nitrogen and things like that. You get a fresher crop that has its natural condition more intact because you're growing it much closer to the environment. That again depends on what you're using as a growing technique. If you're not growing with organic inputs or organic ingredients or typically anything that's plant compatible, you're doing the same thing that traditional

or factory agriculture is doing. And you're not essentially bringing a better product but you're just bringing a product closer to where it is.

Additionally, in compact agriculture, the taste of produce can be adjusted to be more desirable and consistent by altering the growth inputs.

One respondent (an academic), however, mentioned that the shelf life of produce grown in favourable growth conditions is considerably low compared to other types of agriculture. They stated,

The only other problem with hydroponic growth is that its shelf life is really low. Which is good that it is grown locally. It doesn't last as long as field grown. It's because it is grown in cushy conditions. It's a perfect environment that plants don't have to build up any structures to help it survive. So, it's just a weak plant compared to something grown in the field. Fields ones are tough for they've got UV light to contend with and a lot of wind and harsh sun. It's a tough environment so you get tougher plants.

Economic benefit

Seven of the nine interviews touched upon economic benefits related to compact agriculture. Respondents agreed that compact agriculture can become a new source of jobs and create additional employment opportunities. It can be beneficial particularly in cities which have been impacted by de-industrialization. An academic said,

I think those will be the areas where compact agriculture will have a benefit to local communities and local economies because you'll be developing a new industry, putting new capacity into local communities in terms of their technical capabilities and entrepreneurial skills. So, there's some very positive benefits there.

Compact agriculture also seems to be generating interest among the public in agriculture and attracting younger generation. This is because of its possibility of being located within urban centres and more tech oriented. In addition, exposing people to new technologies can lead to further innovation of the food system. A consultant mentioned "Exposing more talent to these new technologies creates new interest and then that creates new innovation and more understanding of the food system."

#### *4.4.3.5 Operational opportunities*

Six interviews talked about operational opportunities for compact agriculture.

Respondents identified knowledge sharing and effective marketing as facilitators from an operational point of view.

##### Knowledge sharing and training

Research and development for different technologies and the possible tech transfer is advancing compact agriculture. A business operator mentioned,

There's been a lot of research and development happening at the universities. Whether the motivating factors are figuring out food for long term space travellers for NASA and Canadian Government or both, adapted quite a bit of research into figuring out food for long term space missions. Can we grow plants in moon and mars and all? It has a direct tech transfer to our interest in growing food in urban environments not only from a point of view of learning how to optimize the environment for a plant and recirculating and limiting the amount of resources needed to grow a plant but also how you could then push that plant in a controlled environment and boost its nutritional content on a fraction of the inputs.

Universities and colleges are also developing programs to impart knowledge of growing food indoors and train individuals for future jobs. Municipality officials gave the example of a large-scale project by University of Toronto and Centennial College.

Businesses and individuals practicing indoor growing are very open and helpful in imparting knowledge to other businesses and individuals. A business operator mentioned "The knowledge that is being learned from the mistakes of the past 8 or so years are starting to get into a rhythm of how to efficiently grow in a compact environment." A business operator and a consultant agreed that with setting up of standard operating procedures (SOPs) and protocols, training people for compact agriculture can become much easier.

Further, many urban dwellers who, having migrated from agrarian countries, know how to grow food and are already growing food as a hobby. Several people who are willing to learn how to grow their own food have an opportunity to learn from these individuals. The

knowledge sharing can help formulate a very essential skill set required for compact agriculture.

#### Marketing the product

Compact agriculture can be marketed more effectively than current practice. A couple of respondents asserted that the unconventionality and value add of compact agriculture commodities can be used in the marketing strategy. For example, the possibility of having food available throughout the year is a value add for compact agriculture. In addition, having certain certifications like GAP (Good Agricultural Practices) or HACCP (Hazard Analysis and Critical Control Points) can also add value to compact agriculture. A business operator also mentioned how social media can be utilized to help compact agriculture move forward.

Understanding compact agriculture's niche market opportunity in terms of supplying perishable commodities to high end restaurants can help it to be economically feasible. An academic stated,

Compact agriculture is necessarily limited to specific especially perishable commodities that suffer from large transportation costs and large distances in various seasons of the year. That will be the market certainly for the next couple of decades I suppose with technology of all. The market will necessarily be isolated to small stature perishable commodities like strawberries and various greens, microgreens and the value added will come from the packaging of multiple crops - the instant salad kind of approach - cherry tomatoes or small stature crops and will probably develop the worst variety of wider range of commodities just to add some variety to the offerings that compact agriculture can bring to the table economically. The small stature and perishable commodities are the ones that will rule, at least for as long as I can foresee at the moment.

#### **4.4.4 CHARACTERISTICS OF CITIES SUITABLE FOR COMPACT AGRICULTURE**

Participants identified several attributes that make cities suitable for compact agriculture. These were extreme weather conditions, market acceptability, high density and population, real estate availability, high income and willingness to spend, and a supportive

regulatory environment. Table 4-4 summarizes the number of interviews and the stakeholder categories which represented these characteristics. They are discussed further below.

Table 4-4. Characteristics of cities suitable for compact agriculture identified by key informants

Characteristics	No. of interviews	Key informant category represented
Extreme weather	5	Business operator, consultant, academic, municipal department
Market acceptability	5	Business operator, consultant, municipal department, NGO
High density and population	4	Business operator, consultant, academic, municipal department
Real estate availability	2	Consultant, NGO
High income and willingness to spend	1	NGO
Supportive regulatory environment	1	NGO

Extreme weather conditions that make conventional agriculture difficult and market acceptability were the most touched upon characteristics. An academic stated,

we have to get into the broader range of commodities and address the perishability issues and address applications in harsh environments on Earth where premiums are charged for perishable commodities. They're typically shipped in long distances such as in Canada's north or in the deserts of the Middle East.... So, there's an opportunity there to take advantage of the potential margins available under those extreme conditions.

In terms of market acceptability, apart from having acceptance for compact agriculture and the right crop portfolio, the urban character and forward-thinking mindset of a city was also discussed. A business operator stated,

It will be a very forward-thinking city. So, one that is preparing itself for the future and how many people it has to feed or any natural disasters that might come up. It's something that's going to help support the economy or even just the safety of the city.

High density and population in a city was also considered as a favourable attribute of cities from a market potential perspective. A research professional mentioned that

“anywhere where the population density is high, you can squeeze these things in and grow it cost effectively”.

Real estate availability in terms of suitability, adequacy and affordability were also touched upon as favourable characteristics. Cities with limited amount of open spaces, enough building stock, and affordable rents were considered more amenable and suitable to compact agriculture. Non-government organization representative also touched upon high income and willingness to spend on compact agriculture produce and supportive regulatory environment including political environment as favourable characteristics in cities for compact agriculture.

## **4.5 DISCUSSION**

### **4.5.1 KEY FINDINGS**

Three key findings emerged from this study. First, the key informants recognize that compact agriculture is poised for explosive growth in the coming years and will create its own niche in the market. Second, key informants’ perceptions of barriers currently seem to outweigh facilitators and opportunities associated with compact agriculture. This is specifically true for economic, regulatory, and operational issues. Third, from a sustainability discourse perspective, key informants have differing views towards environmental and socio-economic impacts of compact agriculture.

#### *4.5.1.1 Compact agriculture will create its own niche*

Compact agriculture is destined to grow. Majority of the happenings in the compact agriculture space are geared towards its advancement. For example, technology used in compact agriculture is quite mature now and its development further will improve overall production efficiency. Cities are also working towards recognizing and integrating compact forms of agriculture in their policies and bylaws.

Most of the respondents argue that compact agriculture can not potentially replace the conventional field agriculture. Field agriculture will always be dominant in terms of producing the four main staple crops of the planet while greenhouse agriculture will lead in growing tomatoes and tall vine crops. However, respondents also suggest compact agriculture can create its own niche in the market. Green leafy vegetables and micro-greens will be the most likely products from compact agriculture. The unconventionality of compact agriculture and its ability to enable access to local and fresh produce in areas lacking the same will aid in making a place for it in the market.

#### *4.5.1.2 Barriers to compact agriculture outweigh its facilitators and opportunities*

The study findings reveal that perceived barriers to compact agriculture currently outweigh the possible facilitators and opportunities. In economic terms, high cost of infrastructure and real estate, lack of capital and access to financial support, high operational costs, and return on investment compared to alternate business opportunities have been discussed as present-day barriers by respondents. This finding is also supported in literature. Specht et al. (2014), and Specht, Siebert, et al. (2016) talk about the issue of high investment costs and competition with economically attractive alternate land uses. However, a few respondents have also talked how sharing production costs and the growing interest to invest in compact agriculture can offset some of the economic barriers.

Respondents in this study were highly concerned with the regulatory issues around compact agriculture. They discussed at length the unsupportive political environment for compact agriculture, the lack of encouraging policies in place, and the general public acceptance of compact agriculture. Respondents' suggestions for advancing compact agriculture line up with those published in the urban agriculture literature. Desjardins, Lubczynski, & Xuereb (2011) and Huang & Drescher (2015b) suggest municipal level policy changes to promote urban agriculture in cities. Mendes et al., (2008) recommended having explicit documentation of urban agriculture in policies and have its own land use designation.



Growing institutional support and cities in the process of adopting compact forms of agriculture in plans, policies, and by-laws can help ease the legal barriers.

There are also many operational issues around compact agriculture. Respondents perceive limitations with current technology, production capacity, knowledge of growing, labour requirements, risk of contamination, and difficulty adhering to regulations as major operational issues at present. Knowledge sharing and learning from other businesses is what key informants see as essential to overcome operational barriers. Effective marketing strategies can also help sell the produce from compact agriculture and fetch higher economic returns.

#### *4.5.1.3 Differing key informants' opinions from a sustainability perspective*

Respondents had different views and opinions about compact agriculture from a sustainability perspective. They referred to compact agriculture as beneficial with respect to some parameters and as detrimental with respect to some other parameters. Compact agriculture was perceived by respondents to have a strong socio-economic benefit and food security was recognized as a common advantage. Caplow (2009), Despommier (2010), Germer et al. (2011) and Specht et al. (2014) also support this idea in their respective research. Some respondents, however, also recognized that food security can be supported through other forms of urban agriculture. This is contrary to some researchers that argue that the issue of food scarcity is more of a result of poverty and unequal distribution of food and urban agriculture cannot possibly address it (Gordon & Richardson, 1997a).

From an environmental perspective, though high consumption of energy and issues with waste generation in compact agriculture were recognized as barriers, improved resource efficiency, reduced food miles, and reduced land impact were the purported benefits. Goldstein et al. (2016b) recognized the same in their research. Few respondents' claims that the reduced food miles in compact agriculture can not offset the overall energy consumption is also supported in literature (Li et al., 2016).

#### **4.5.2 STRENGTHS AND LIMITATIONS**

This study adds to the limited literature available on the topic of compact agriculture. Intended to uncover the perceived barriers and facilitators to compact agriculture in the City of Toronto, this study is also transferable to other geographical contexts. It informs the research family on the current state and perceived future for compact agriculture. The findings from this research justify the need for cities to be ready for compact agriculture implementation and can help municipal department officials frame the required regulatory framework for it in order to maximize the environmental and socio-economic benefits.

However, there were certain limitations associated with this study. First, some of the key informant categories were not represented. These were citizens, public authorities, and businesses like restaurant industry and competing industries (traditional and greenhouse agriculture). Second, because of the novel nature of compact forms of agriculture, the respondents' understanding of the terminologies may not have been consistent throughout. This was addressed through the researcher's interpretation of the interviews.

#### **4.6 CONCLUSIONS**

In extant literature, there is ambiguity in compact agriculture's advantages and disadvantages. This is due to the lack of research in this space. This study used qualitative interviews to explore key informants' perceptions on the state of compact agriculture and barriers, facilitators, and opportunities for compact agriculture. The results revealed that compact agriculture is destined to create its own niche in the food production system.

Another finding disclosed that at present the barriers for compact agriculture are more prominent than the facilitators. Planners can help ease the regulatory barriers by recognizing compact agriculture forms in policies and bylaws. Access to affordable capital and grants for compact agriculture businesses can relieve the economic hurdles. Operational barriers are expected to ease over time with more experience and knowledge in

the field. Respondents had diverse opinions on sustainability of compact agriculture. This may be because of lack of empirical evidence and varied experiences of the respondents with compact agriculture.

Considering the limitations of this study, it is suggested to include the missing key informant categories in future research. Another suggestion is to undertake a policy analysis of different cities in Canada. This may reveal a better understanding of the regulatory environment with respect to compact agriculture.

The findings are based on what key informants currently think. However, with technological advances, policy changes, and climate change, the favourable conditions may very well change and improve for compact agriculture.

## **CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS**

This chapter serves as a conclusion and synthesis of the two manuscript chapters that were presented in this thesis. The principal findings from the two manuscripts are discussed first. Then recommendations are made for future researchers, decision-makers, and businesses in terms of how they can proceed with sustainable implementation of compact agriculture.

### **5.1 PRINCIPAL FINDINGS**

The need for this research stemmed from the gaps identified in the literature review on compact agriculture. One of the literature review findings was the lack of empirical evidence strongly in favour or against compact agriculture. Instead, there is currently a diverse discourse amongst researchers on the potential impacts of compact agriculture, and a need to compare compact agriculture with conventional agriculture from an environmental perspective. Chapter 3 (Manuscript 1) of this thesis titled “Compact Agriculture versus Conventional Agriculture: Learnings from a Comparative Life Cycle Assessment” used an LCA framework to deduce the environmental impacts of compact agriculture compared to conventional agriculture.

The literature review also found that though there are many positive effects of compact agriculture from a socio-economic standpoint, there are hurdles for compact agriculture in Canadian cities. This finding required to explore the barriers and facilitators of implementing compact agriculture in Canadian cities. Chapter 4 (Manuscript 2) of this thesis titled “Perceived Barriers and Facilitators for Compact Agriculture in Canada: An Exploration of Multi-sector Key Informant Perspectives” used qualitative interviews with various key informants to deduce their perceived barriers and facilitators for implementing compact agriculture.

The principal findings from the two manuscripts are revisited in the sub-sections below. This is followed by a synthesis of the key findings.

*Chapter 3: Manuscript 1 – Compact Agriculture versus Conventional Agriculture: Learnings from a comparative Life Cycle Assessment*

The LCA study comparing compact and conventional agriculture for City of Toronto found that compact agriculture, despite having lower food miles, has higher environmental impact potential in terms of global warming, acidification, eutrophication, and resource depletion potential. The proximity to end-consumer to avoid impacts associated with food miles would not offset the impacts due to the immense electrical consumption in compact agriculture in Toronto. The study illustrates that improvement in production of electrical energy to accommodate cleaner renewable sources such as solar, wind, and hydro can make compact agriculture potentially more environmentally sustainable than conventional agriculture.

*Chapter 4: Manuscript 2 – Perceived Barriers and Facilitators for Compact Agriculture in Canada: An Exploration of Multi-sector Key Informant Perspective*

Semi-structured interviews with multi-sector key informants to explore the perceived barriers and facilitators showed that at present there are more perceived barriers than opportunities for compact agriculture implementation in Canadian cities. The study identified high set-up costs, return on investment, lack of financial support, ambiguity in public acceptance and political environment, and lack of implicit recognition in policies as major barriers to market entry for compact agriculture businesses.

The key informants had mixed opinions on environmental and socio-economic barriers and facilitators. High consumption of energy, issues with unprecedented waste generation, and impact on surroundings and employment were perceived as potential issues. However, improved resource efficiency, reduced food miles and land impacts,

improved food security, and overall economic benefit were the perceived facilitators from a sustainability discourse standpoint. In addition, key informants also recognized operational barriers to sustaining compact agriculture businesses, the major ones being technology, knowledge, production capacity and labour limitations.

The key informants also acknowledged a place for compact agriculture in the future food system. They accepted that it will not be able to replace conventional and greenhouse agriculture but will be able to create its own standing in the market supplying certain crops (micro-greens and green leafy vegetables) to sections of the society that are more considerate of how their food is produced, where it comes from, and how it impacts the environment. Growing institutional and financial support, cost sharing initiatives, knowledge sharing, and effective marketing strategies were recognized as some facilitators and opportunities which could help compact agriculture growth in Canada.

## **5.2 RECOMMENDATIONS**

Both manuscripts in this thesis, the LCA study and the key informant' interviews, suggested that conventional agriculture is better than compact agriculture at present. However, the world is rapidly urbanizing, and cities are sprawling over arable land. In addition, technology is advancing at an exponential pace and cleaner forms of energy production are being adopted. Therefore, although things seem dire for compact agriculture, the rapidly changing phenomena can change things quickly. Compact agriculture could become an important future focus for food systems. It therefore becomes essential to get ahead of the curve and be proactive towards compact agriculture.

Findings from this thesis are relevant to researchers, decision-makers, and compact agriculture businesses. This thesis contributes to the limited scholarship on compact agriculture in Canada. While the existing research discusses the impacts of compact

agriculture theoretically, this thesis provides quantitative (manuscript 1) and qualitative insights (manuscript 2) into the barriers and facilitators of implementing compact agriculture. However, we suggest researchers to consider the limitations and scope of this work for future research.

### **5.2.1 STUDY LIMITATIONS AND FUTURE RESEARCH**

There were several limitations to the study. The comparative LCA between compact and conventional agriculture for the City of Toronto in manuscript 1 was modelled on numerous assumptions. The system boundaries excluded the infrastructure used and transportation of agricultural inputs in the two production systems. Further, romaine lettuce was the commodity used for comparison. In addition, greenhouse production system was not considered in the study. It is recommended that future studies look at a more comprehensive comparative LCA study including greenhouse agriculture infrastructure requirements in different product systems. Different types of compact agriculture should also be compared for sustainability.

The key informant' interviews in manuscript 2 had some limitations as well. Key informant categories such businesses utilizing produce from compact agriculture facilities were left out. Researchers can also look at incorporating missed out key informant categories to achieve a more holistic view on perceived barriers and facilitators for compact agriculture. A stand-alone study to assess consumer acceptance of compact agriculture can also be conducted. Further, researchers can create best practices documents from successful businesses in the world for knowledge sharing and advancement of compact agriculture.

### **5.2.2 RECOMMENDATIONS FOR DECISION-MAKERS**

Decision-makers can play an important role in advancing compact agriculture. At present, compact agriculture is not explicitly recognized in policy. Therefore, it is

recommended that decision-makers recognize and define compact agriculture in official plans and zoning bylaws. Since different types of compact agriculture systems can be producing different commodities, their impact on the environment can be very different. Decision-makers can require businesses to conduct comparative life cycle assessment to assess the environmental impact and compare it with business as usual scenario. However, this may add to the financial burden of the business. Therefore, it is also recommended that decision-makers provide financial support to businesses showing positive social, economic, and environmental impacts.

### **5.2.3 RECOMMENDATIONS FOR BUSINESSES**

Businesses should conduct location and commodity specific life cycle assessment studies and compare its environmental impact with conventional system. Their objective should strive to provide a net positive socio-economic and environmental benefit in order to gain public and political support. New businesses should try and learn from those who have failed and those who have been successful. Innovative cost sharing strategies could also help offset financial burden. A suggestion is to explore the option of incorporating compact agriculture in residential or commercial buildings where the cost of running the facility can be included in the maintenance fee charged from tenants. Effective marketing strategies should also be implemented to grow customer awareness.



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## APPENDICES

Appendix A. LCIA results of 1 kg packaged compact lettuce and 1 kg packaged conventional lettuce at retail gate by Eco-indicator 99 (I)

Impact category	Compact Lettuce	Conventional Lettuce
Human Health - Climate change (DALY)	3.38E-02	1.60E-02
Ecosystems Quality - Acidification and Eutrophication (PDF*m <sup>2</sup> *yr)	3.54E-02	1.78E-02
Human health - Ozone layer depletion (DALY)	2.06E-10	5.09E-10

Appendix B. LCIA results of 1 kg packaged compact lettuce and 1 kg packaged conventional lettuce at retail gate by ReCiPe midpoint (I) v1.11

Impact category	Compact Lettuce	Conventional Lettuce
Climate Change (kg CO <sub>2</sub> eq)	3.05E+00	1.52E+00
Terrestrial acidification (kg SO <sub>2</sub> eq)	9.70E-03	3.66E-03
Freshwater eutrophication (kg P eq)	1.03E-03	1.86E-04
Marine eutrophication (kg N eq)	9.59E-04	1.53E-03
Ozone depletion (kg CFC-11 eq)	2.56E-07	6.31E-07
Fossil depletion (kg oil eq)	8.55E-01	4.33E-01

Appendix C. Interview Guide

Construct Assessed	Questions to the Participant	Probes
<b>Professional standing</b>	What is the title and nature of your work?	What sector do you work in?
	How long have you been working in your current job?	
	Have you been involved in prior positions that have been relevant to agriculture?	Can you describe the nature and scope of that work?
<b>Understanding of the concept</b>	What is your understanding of the terms – indoor agriculture, controlled environment agriculture, vertical farming, plant factories, building-integrated agriculture?	Can you think of any technologies that may fall into this concept?
	If I use the term “compact agriculture”, would you think of something similar or different? Can you explain more on that?	How would you differentiate between “compact agriculture” and the other terms discussed earlier?
	What examples would you give of controlled environment agriculture or compact agriculture?	Are there any other terms you would use to describe the examples you’ve given so far?
<p><b>This study focusses on “compact agriculture” understood as a concept of growing produce in a highly controlled environment utilizing artificial lighting and ventilation. Concepts like shipping container farms, plant factories, and vertical farms where the growth environment is human regulated will be included in this concept. Concepts such as farming on walls and rooftops or even greenhouses and community gardens where the environment may be partially controlled are excluded from the definition and understanding of “compact agriculture” for this study.</b></p> <p><b>Rest of the conversation will be about THIS concept of compact agriculture.</b></p>		
<b>Perspective on the concept</b>	How suitable do you think “compact agriculture” is for the City of Toronto?	In what ways do you think compact agriculture is/is not suitable for Toronto?
	What kinds of cities do you think would be better suited to compact agriculture?	What are the key features of cities that make them suitable for compact agriculture?
	How do you think compact agriculture would compare to	What advantages or disadvantages do you think

	<p>the present conventional and greenhouse agriculture/food system in terms of-</p> <ul style="list-style-type: none"> <li>- Environmental impact</li> <li>- Local food availability</li> <li>- Nutrition</li> <li>- Economic opportunities</li> <li>- Employment opportunities</li> <li>- Dealing with land use pressures</li> <li>- Socio-economic impact (e.g. connecting people with food production)</li> </ul>	<p>compact agriculture would have over the existing food system?</p>
<p><b>Insights into barriers and facilitators</b></p>	<p>What do you think about the growth of compact agriculture businesses in Canada and the City of Toronto?</p> <p>Has it been slow or fast growth from your perspective?</p> <p>What are the barriers and facilitators for implementing compact agriculture in Canada?</p>	<p>To what extent do existing policies support the development of compact agriculture in Toronto?</p> <p>To what extent does the level of acceptance among farmers, producers, consumers, politicians, lobbyists support the development of compact agriculture?</p> <p>To what extent do you think that (production/supply/waste) limitations like production capacity, supply chain, waste management related to compact agriculture confine the development of compact agriculture?</p> <p>To what extent do you think that access to and/or development of technology plays a part in implementation of compact agriculture?</p> <p>To what extent does feasibility of compact agricultural farms and their management play a role in development of compact agriculture?</p>
	<p>Do you think there are any other barriers and/or facilitators wrt</p>	

	implementation of compact agriculture in Canada?	
<b>Capturing data</b>	<p>Are you aware of any data set or documents that could be used to compare compact, conventional and greenhouse agriculture?</p> <p>If yes –</p> <p>What is the data or document?</p> <p>Do you know if that is accessible or not? If it is accessible, how can I get access to it?</p> <p>If no –</p> <p>Move to next question</p>	Production data – inputs and outputs in terms of raw materials, energy, waste, recycling?
<b>Snowball sampling</b>	<p>As you know, I'm interested in speaking with a number of different stakeholders who are interested in compact agriculture. Are you aware of individuals or organizations who might also be interested in speaking with me about compact agriculture?</p> <p>If yes –</p> <p>If you are comfortable would you mind forwarding my recruitment email or contact details to them?</p>	Planners, councilors, non-government/non-profit organizations, business operators?