INSTITUTO TECNONÓLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

FINAL PROJECT REPORT

The Impact of Urban Agriculture in Sustainable Cities.

Author(s):
A01169284 - Bruno González Soria
A01212611 - Antonio Osamu Katagiri Tanaka
A01750267 - Carlos Cardoso Isidoro

Instructor(s):
Diego Fabián LOZANO García
Rosa María LÓPEZ Franco

A project report submitted in fulfillment of the requirements for the course of Leadership for Sustainable Development

in

ITESM Campus Estado de México
School of Engineering and Sciences

Estado de México, Atizapan de Zaragoza, May 11, 2019

INSTITUTO TECNONÓLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

Abstract

Faculty: Nanotechnology

School of Engineering and Sciences

Leadership for Sustainable Development

The Impact of Urban Agriculture in Sustainable Cities.

by **A01169284** - Bruno González Soria
A01212611 - Antonio Osamu Katagiri Tanaka
A01750267 - Carlos Cardoso Isidoro

The debate on the role of urban agriculture in the sustainable city discourse remains unresolved in the conventional literature. Therefore, the purpose of this study was to review relevant literature to clarify the role of urban agriculture in sustainable cities. The search for literature was guided by themes such as: a) urban agricultural practices, b) indicators for the measurement of sustainable cities, c) economic, social and environmental benefits of urban agriculture, and d) negative effects of urban agriculture on the city. The results from a synthesis of the literature indicate that urban agriculture supports the economic, social and environmental sustainability of cities. However, if the discussion gives credence to only the economic dimension of sustainability, then urban agriculture loses the debate. This is because the economic benefits of prime city land that is used used for nonagricultural purposes (such as commercial or industrial) is profound. However, the social and environmental functions of responsible urban agriculture, particularly in reducing the rift between urbanisation and nature, may be difficult to quantify. These social and environmental functions underscore the importance of urban agriculture in the city landscape. The paper concludes by arguing that focussing on only economic sustainability in the urban agriculture-sustainable city discourse is a travesty of the idea of sustainable development. The paper presents practical steps that can be taken to preserve agriculture in cities towards their sustainability.

keywords: sustainable cities, compact cities, urban agriculture, urban land use planning

Contents

Abstract **i**

1 Introduction **1**

2 Conceptual Framework **5**

2.1 Overview of urban agriculture 5

2.2 Conceptualising a sustainable city 6

2.2.1 The Green City Index 9

2.2.2 Global City Indicators Facility 10

2.2.3 Global Compact Cities Circles of Sustainability 11

3 Methods **13**

4 Analyses **15**

4.1 Urban agriculture and economic sustainability of cities 15

4.1.1 Full-time employment 15

4.1.2 Employment for women 17

4.1.3 Income generation and gross domestic product 18

4.1.4 Savings and expenditure 19

4.1.5 Tax revenue 21

4.2 Urban agriculture and social sustainability of cities 22

4.2.1 Educational functions 22

4.2.2 Civic engagement 23

4.2.3 Safety and security 24

4.2.4 Gender equality and social equity 25

4.2.5 Health benefits 26

4.2.6 Recreation 27

4.2.7 Technology and innovation promotion 27

4.3 Urban agriculture and environmental sustainability of cities 28

4.3.1 Management of emissions 28

4.3.2 Water management 29

4.3.3 Waste management 30

4.3.4 Energy efficiency 31

4.3.5 Organic farming in percentage of total agricultural area 32

5 Discussion **34**

5.1 Urban agriculture-sustainable city nexus 34
5.2 Implications for cities in the global south and compact cities 36

6 Conclusion **39**

A The Green City Index **44**

B Global City Indicators Facility **48**

C Global Compact Cities Circles of Sustainability **55**

List of Figures

3.1 Sustainable City Framework 14

4.1 Carbon Nano-wires Fabrication Process 16

1 Introduction

Globally, urban land attracts very high rent. This is attributed to rapid urbanisation and ease of accessibility (Trussell, 2010). Consequently, farmers who are unable to compete for lands due to their low bid rents, have been priced out of the urban land market (Amponsah, Vigre, Schou, Braimah, & Abaidoo, 2015a; Drechsel et al., 2008; Owusu, Bakang, Abaidoo, & Kinane, 2012). This is the central position of the William Alonso's bid-rent theory. The theory explains how land users are willing to pay high rents for an area of land in an open and competitive land market. Similarly, the theory of 'highest and best use' has been used to justify the allocation of city lands to uses that command high bid rent (Babcock, 1932; Barlowe, 1972; Fisher & Fisher, 1954). The theory expresses the need to allocate city land to uses that produce the largest net income over a given period of time (Fisher & Fisher, 1954). Therefore, city authorities give prominence to nonagricultural uses on the scale of city land allocation preference. Consequently, agriculture has been confined to the urban periphery and rural areas where the value of land is within the means of agricultural land users.

However, rapid urbanisation and its attendant sprawl, particularly in the global south, are threatening the sustainability of agriculture even at the urban periphery (Amponsah et al., 2015b; Liu, Yang, Li, & Li, 2017). Projections by the United Nations indicate that by 2020, the developing countries of Africa, Asia and Latin America will be home to approximately three in four urbanites, and eight of the anticipated nine mega-cities in the world. Furthermore, by 2030, approximately twothirds of the world's population will live in cities. The expected increases in the city population will have implications for high demand for urban lands leading to their allocation to the highest and best use. Furthermore, agricultural land uses in the urban periphery will continue to be invaded by the more competitive land uses, which could have dire consequences on food security and poverty levels (Hoornweg & Munro-Faure, 2012).

From the discussion, urban agriculture can only be sustained if city authorities consciously integrate agriculture into the city land use planning and zoning processes. Nevertheless, the city authorities, particularly in the global south, have given little to no attention to agriculture despite their resolve to make their cities sustainable (evident in the Sustainable Development Goal 11). This could be explained by their apparent belief that the highest and best use of city land is not to allocate it to agricultural uses. This belief may have been fuelled by the lack of clarity in the narrative in the conventional literature about the role of urban agriculture in building sustainable cities. The literature on the effects of urban agriculture is contested between two divides. The first maintains that agriculture in cities performs economic, social and environmental functions, which contribute to the sustainability of cities. For instance, agriculture in cities in Sub-Saharan Africa supplements the nutritional needs of urbanites and reduces their food expenditure (Binns & Nel, 2013). In Yaounde in Cameroon, urban farmers consume almost a quarter of the vegetables they produce (Prain & LeeSmith, 2010), whereas in Ghanaian cities, urban vegetable farmers supply almost all the exotic vegetables (lettuce and spring onion) that are consumed in the cities (Darkey, Dzoemku, Okorley, Gyimah, & Bluwey, 2014; Drechsel & Keraita, 2014). The works of Ackerman et al. (2014), Opitz et al. (2016), Specht et al. (2013) and Ayambire et al. (2019) also highlight the role of urban agriculture in food security.

Besides the economic functions, urban agriculture is known to perform social and environmental functions. The environmental functions are in the forms of air and water quality enhancement (Lin, Philpott, & Jha, 2015), and pollination and biocontrol activities (Camps-Calvet, Langemeyer, Calvet-Mir, & Gómez-Baggethun, 2015; Lin et al., 2015). The social functions are evident in its support for political activism and volunteerism in cities. For example, a study showed that farmers in New York City are more likely to engage in voluntary works for community development than the general population (Obach & Tobin, 2014; Pole & Gray, 2013). Also, farms in Dar es Salaam in Tanzania serve as rallying grounds for political parties during election years (McLees, 2016). Dimitri et al. (2016) note that urban farms provide educational and community building functions (e.g. social missions).

The discussion points to the profound role of urban agriculture in the sustenance of cities. This is, however, in contrast with the position of the scholars who maintain that the contribution of urban agriculture to city sustainability is not momentous. For instance, Veenhuizen (2006) suggests that urban agriculture may increase the burden on women as they combine their household duties with agricultural activities. In addition, urban agriculture, particularly in the global south, has been known to fuel child labour and truancy in school (Edet & Etim, 2013; International Labour Organization, 2006). Furthermore, the excessive use of agro-chemicals (Obuobie et al., 2006; Yamusa, 2014) and/or the use of untreated wastewater for unrestricted irrigation (Amponsah, Vigre, Schou, Braimah, & Abaidoo, 2015a; Becerra-Castro et al., 2015; Mara & Sleigh, 2010; Ndunda & Mungatana, 2013) are known to have adverse health and environmental consequences. The discussion reveals the two-sides of the discourse on the role of urban agriculture in the sustainability of cities.

Based on the theory of 'highest and best use' and the arguments against urban agriculture, city authorities, particularly those in the global south, make little attempts to integrate agriculture into the city land use planning and zoning processes. For instance, Amponsah et al. (2015a, 2015b) point out that city authorities in Kumasi and Accra in Ghana do not include agriculture in the land use plans of the cities. Their emphasis has rather been on land uses that have high bid rents because these lands are perceived to promote the 'highest and best use' of urban land in tangible terms. However, using net income over a given period of time from tangibles (Fisher & Fisher, 1954) as the determinant of highest and best use of land may be misleading. The difficulty in measuring the present value of social and environmental services may lead to an underestimation of the importance of urban agriculture. In this case, the picture portrayed of urban agriculture in the city sustainability discourse may not be whole. The aim of this paper, therefore, was to attempt to clarify the nexus between urban agriculture and sustainable cities by considering the arguments for and against urban agriculture.

The paper is structured into six parts. The first is the introduction, which highlights the unresolved arguments for and against urban agriculture. The second section covers a conceptual framework for sustainable cities. The third section presents the materials and methods while the fourth covers an assessment of the nexus between urban agriculture and sustainable cities. The fifth section presents a discussion of the results of the study and their implications for city land use planning while the sixth presents the conclusion of the study.

2 Conceptual Framework

This section of the article opens with an overview of urban agriculture and ends with a conceptual framework for sustainable city.

2.1 Overview of urban agriculture

The Food and Agricultural Organization (2003) defines urban agriculture as any production in the home or plots in an urban area. Central to this definition is the understanding that urban agriculture assumes the nature of farming and gardening in rural areas (Opitz, Berges, Piorr, & Krikser, 2016). Whether to consider peri-urban agriculture as part of urban agriculture or not is a subject that remains unresolved in the conventional literature. While some scholars and organisations limit their description of urban agriculture to only gardens and farms within the inner city (Cohen, Reynolds, & Sanghvi, 2012; Howe, 2002; Kaufman & Bailkey, 2000), others describe it to include agricultural activities in the peri-urban areas (Mok et al., 2014; Pearson, Pearson, & Pearson, 2010; Van der Schans & Wiskerke, 2012). Thebo, Drechsel, and Lambin (2014) make a clear distinction between urban agriculture and peri-urban agriculture based on geographical location. The authors indicate that peri-urban agricultural activities take places within a buffer of 10 to 20 km of the urban geographic boundary. Based on this distinction, the present study focuses on only agricultural activities that take place within an urban geographical boundary or is within 10 km range from a city's core. The work of Ayambire et al. (2019) gives a detailed distinction between urban and peri-urban agriculture.

The purpose of urban agriculture differs between cities in the global south and those in the global north. In the latter, people farm typically for recreational or aesthetic reasons although farming for household food supply becomes pervasive during economic meltdowns (McClintock, 2010). In the former, farming is mainly to satisfy household food needs and for other commercial reasons (Amponsah, Vigre, Braimah, Schou, & Abaidoo, 2016; McClintock, 2010; Tornaghi, 2015). Typically, households in the cities in the global south farm on undeveloped lands, marginal lands and community plots mainly for food for household consumption whereas empty spaces of post-industrial landscapes are being used for agricultural purposes. Rooftops, balconies and more recently vacant lots, road medians, and parks are used for agricultural purposes in the cities in the global north (McClintock, 2010). In this context, urban agriculture is used in the present study to typify crop farming done through community gardens, allotments, backyard gardens and rooftop gardens.

2.2 Conceptualising a sustainable city

The concept of sustainable cities has its roots in the United Nations World Commission on Environment and Development's (UNWCED) idea of sustainable development. The UNWCED summarised sustainable development as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. The concept has been a standard to strive for in many areas of human activity (Filion, 2017). It is a normative concept that determines theway humans should act towards nature, as well as the way they should be responsible towards one another and future generations (Baumgärtner & Quaas, 2010; Yigitcanlar & Dizdaroglu, 2015). However, Lew, Ng, and Ni (2016) suggest that numerous definitions of sustainability and sustainable development are sometimes sloppy, vague and narrow. This is partly due to the varied understanding of sustainable development and the numerous semantics in the institutional, ideological and academic definitions of sustainability (Mebratu, 1998). For instance, environmental economists believe in economic reductionism by undervaluing ecological goods while social ecologist is reductionist-holistic by focusing on the domination of people and nature. These believes translate into their conception of sustainability and sustainable development. Mebratu (1998), therefore, concludes from the varied conceptions particularly on the cosmic perceptions about the separate existence of nature, economy and society, are problematic for sustainability research. Again, the conceptual understanding and perception of the environment (which comprises living and non-living things) and ecology (which refers to the relationship between living organisms and their environment) as synonymous has affected and continues to affect the conceptual understandings of sustainable development. These can undermine the understanding of a sustainable city since they are intertwined. For clarity, this study's focus on sustainable development considers its tripartite dimension (economic, social and environmental).

In recent times, the sustainable city concept has assumed prominence. This is evident in the Sustainable Development Goal [SDG] 11, which is "to make cities and human settlements inclusive, safe, resilient and sustainable". The concept's growing prominence is fuelled by rapid urbanisation of the world and the associated effects on environmental quality. The implication is that sustainability should be a crucial objective every development endeavour should strive to achieve (UNHabitat, 2013). In this regard, the primary goal of urban development should be to make cities and their ecosystems healthy and sustainable (Hiremath, Balachandra, Kumar, Bansode, & Murali, 2013; Jovanovic, 2008; Smith, 2015; Thornton, 2011). However, the discourse on urban development and urban sustainability has resulted in a plethora of studies equating the sustainable city concept to the new vision of a compact city. This seems to be a conceptual contention like the definition of sustainable development.

The main idea behind the compact city concept is to have a city that is energy-efficient and less polluting because of the proximity of houses to the market centres, shops and work places (Neuman, 2005). The focus is on compactness, which will result in less travel, efficient use of public transportation and ultimately reduce emissions (Abdullahi, Pradhan, Mansor, & Shariff, 2015; Chang, 2016). Typically, compact cities have less space for green-infrastructure due to the inherent physical and institutional obstacles that limit the quantity and quality of amenity vegetation (Jim, 2004). Studies have also shown that compactness can have adverse effects on domestic living space, affordable housing, and increased crime levels (Chhetri, Han, Chandra, & Corcoran, 2013; Lin, Lin, & Yang, 2006). These effects are contrary to the principles of a sustainable city, which emphasise a balance among economic development, environmental protection, and equity in income, employment, shelter, basic services, social infrastructure and transportation (Hiremath et al., 2013). In this regard, we do not use a compact city interchangeably with a sustainable city in the present study.

The confusion between sustainable city and compact city prompted the authors of this study to provide a clear and comprehensive picture of the meaning of a sustainable city. As stated earlier, the nuanced conception of sustainable development affects the meaning of a sustainable city. This results in the concentration of indicators that reflect a limited number of dimensions (Tanguay, Rajaonson, Lefebvre, & Lanoie, 2010). However, Hellstro (2000), concludes that it would be unfeasible to try to compile all indicators from all available databases. Therefore, scholars tend to specify on some criteria/indicators based on the focus of their studies and their ideological orientations. For instance, Hellstro (2000) proposed a six study-specific criteria for measuring sustainable urban water management. These criteria are: a) health and hygiene, b) cultural contribution, c) spreading of toxic compounds to water and soil, d) use of natural resources, e) cost benefits, and f) functional risk. The criteria are study-specific and not crosscutting. Many other scholars and organisations use a variety of criteria to define sustainable cities (see: Green City Index, Global City Indicators Facility and the Global Compact Cities Circles of Sustainability). The nuances in the sustainable city indicators are attributable to varied conceptual understanding of a sustainable city discussed above (Alberti, 1996; Egger, 2006; Evans & Marvin, 2006; Portney, 2002).

Models and indices are also backed by conceptual views. As such, there is the need to try to complement the strengths and weaknesses of several indicator-sets to derive a more robust and comprehensive model for measuring sustainable city. The use of indicators is also relevant because they provide a much more detailed and quantitative way of measuring the sustainability of a city. Therefore, in this article we review some of the existing models (the Green City Index, Global City Indicators Facility and the Global Compact Cities Circles of Sustainability) to develop a framework that adequately identifies the indicators for a sustainable city. This framework serves as the basis for the discussion of the role of urban agriculture in sustaining cities.

2.2.1 The Green City Index

The Green City Index is regarded as one of the robust models for the identification of a sustainable city (Huang, Wu, & Yan, 2015). It comprises 30 indicators, which are grouped under eight categories. These categories are a) environmental governance, b) carbon dioxide (CO2), c) buildings, d) transport, e) water, f) waste and land use, g) energy and h) air quality (refer to Supplementary Table 1). The strength of this model lies is its ability to be applied in several geographical contexts. The index has been the basis for the following reports: African Green City Index, Asian Green City Index, European Green City Index, German Green City Index, Latin American Green City Index, and U.S. and Canada Green City Index (Huang et al., 2015). The wide application of the model, its comprehensiveness and attribute as a "strong sustainability indicator" Huang et al. (2015, p. 14), were the main reasons for considering it in this paper.

Furthermore, there are some inherent linkages among the suggested indicators. One indicator has effects on the outcome of another. For instance, the indicators on carbon dioxide (CO2), which aims to reduce emissions, are directly linked to the indicators on transportation and air quality. The use of non-car transportation and increased use of green transport will most likely result in the improvement of air quality. This can also lead to the strengthening and sustenance of a green action plan. Again, the indicators on energy are directly linked to the indicators on buildings. The management of energy consumption and the increase in the use of renewable energy are most likely to translate in energy efficient buildings if used in those structures.

However, there are some complications with the use and measurement of some qualitative words such as comprehensiveness, ambitiousness and extensiveness. Without clarity on how these words are measured, the use of the model to conceptualise sustainable city leads to inconclusive and subjective outcomes. Another weakness of the model is its overemphasis on energy and CO2 emissions with little attention to measures of health, happiness and quality-of-life (Science for Environment Policy, 2015). Sahely and Kennedy (2007) also observed that the model, like many of the in-vogue models, focusses primarily on environmental impacts and do not include an extensive treatment of economic and social issues. However, the assumption underpinning this model is the tripartite relation among the environment, economy and society. This means that the indicators suggested in the Green City

Index could have spill-over benefits. For instance, being able to comply to the standards set by the indicators can improve standard of living in cities. Managing emissions, waste production and water has implicit implications for health, safety and the economy. Therefore, not being explicit on health, happiness, quality of life indicators and the supposedly limited attention to economic and social issues arguably do not undermine the relevance of the Green City Index for measuring sustainable cities. However, the lack of direct and conspicuous consideration for health, happiness, and quality of life indicators makes the model amendable to varied application and ultimately challenges its relevance for holistic city planning purposes. To address the rather obvious weaknesses, the review covered the Global City Indicator Facility, which mainly covers the social aspects of urban life

2.2.2 Global City Indicators Facility

Unlike the Green City Index, the Global City Indicators Facility attempts to cover all aspects of urban life, with significant emphasis on economic and social measures of sustainability (refer to Supplementary Table 2). The model conceptualises a sustainable city based on strong economic and social structures. The Global City Indicators Facility was created by the World Bank, working with the Japanese Trust Fund. Compared with the Green City Index, its weakness lies in the limited focus on pollution or air quality, CO2 emissions, clean and renewable energy consumption and environmental governance. However, if cities consider indicators on wastewater, water and particulate matter emissions as suggested in the Global City Indicators Facility, they may accrue direct and external benefits to capture all the environmental indicators suggested by the Green City Index. In addition, the Global City Indicators Facility was designed to focus on cities with over 100,000 inhabitants and lacks a standardisation, which makes it difficult for cities to share best practices and learn from each other (McCarney, 2009). However, this does not dispute its importance in the sustainable city discourse. In fact, Fox and Pettit (2015) state that the goal of the Global City Indicators Facility is to attain a common set of indicators for all cities globally. This makes the Global City Indicators Facility relevant in the sustainable city discourse.

In another vein, the Green City Index and the Global City Indicators Facility agree on the use of specific indicators such as particulate matter concentration, solid waste, transportation, wastewater, water consumption and energy. However, they do not cover aspects of embodiment and enough food and flora and fauna. These are essential requirements for sustainable cities (Ackerman et al., 2014; Opitz et al., 2016; Specht et al., 2013). The implication is that the Green City Index and the Global City Indicators Facility complement each other to identify a robust set of indicators to measure the sustainability of cities. The weaknesses in these models and the earlier contentions in the literature on compact cities and sustainability precipitated the review of the Global Compact Cities Circles of Sustainability.

2.2.3 Global Compact Cities Circles of Sustainability

The Global Compact Cities Circles of Sustainability is a method used for assessing the sustainability and for managing projects directed at socially sustainable outcomes. It has been used by several cities such as Johannesburg, Melbourne, New Delhi, São Paulo and Tehran and by several organisations such as the UN Global Compact Cities Programme, World Vision and Save the Children to understand and support sustainability efforts (KPMG International, 2016). It is based on 28 indicators (refer to Supplementary Table 3), which are subdivided into four broad categories. These categories are politics, culture, economics and ecology. A scale of critical, being the least, and vibrant, being the best, is used alongside the indicators to rank development efforts.

The inadequacies of the Green City Index and the Global City Indicator Facility in not providing for embodiment, sufficient food and flora and fauna have been covered by the Global Compact Cities Circles of Sustainability. The strength of this index is its global list of indicators as well as its suitability for different countries. An analysis of the Global Compact Cities Circles of Sustainability shows some similarities with the Green City Index and Global City Indicators Facility in terms of the considerations they give to health, education, gender, technology, infrastructure, waste, water and air. Again, the indicators under the Global Compact Cities Circles of Sustainability are complementary. For instance, actions targeted at reducing emissions and waste are more likely to improve the habitat, settlements, recreation, identity and organisation of an area. However, the Global Compact Cities Circles of Sustainability, unlike the Green City Index and the Global City Indicators Facility, does not cover into details the aspects of environment, energy management and civic engagement.

Relevant as these and many other models (such as the Improvement and

Efficiency Social Enterprise (IESE) Cities in Motion Index, Gross National Happiness Index and Sustainable Society Index) are in the measurement of the sustainability of a city, the indicators used to measure a city's sustainability vary. This is evident in the observed differences in indicators among the three models covered in this study. This is because the way systems and a city function depend on information flows within them (Meadows, Randers, & Meadows, 2004). Therefore, choosing which indicators to measure is a crucial determinant of the behaviour of a system or city (Meadows, 1998). Due to this, some suggestions have been made on how to measure a sustainable city since all the indicators are not fixed and applicable in all places and situations. For instance, Tanguay et al. (2010) suggest a method of survey-based selection strategy for Sustainable Development Indicators (SuBSelec). Here, researchers must: a) choose the most cited indicators, b) cover the components of sustainable development and the pertinent predetermined categories and c) choose the simplest sustainability indicators to facilitate data collection, understanding and dissemination. Furthermore, Olsson, T., Aalbu, and Bradley (2004) suggests the need to make sure selected indicators are: a) relevant to decision making, b) clear in value, c) adequate in scope, d) feasible, e) simple, f) adequately communicated, g) democratic, h) multidimensional, i) distributional, j) forward looking, k) physical, and l) comparable. However, Olsson et al. (2004), recognised the difficulties in indicators meeting all the above listed criteria; thus, concluded that the criteria should serve as a guide not a standard in selecting the most applicable.

The criteria presented by scholars (such as: Olsson et al., 2004; Tanguay et al., 2010) as well as the suggestion by Hellstro (2000) served as a guide in selecting the indicators for this study. For this reason, the paper presents a framework that merges the indicators for measuring a sustainable city to cover the economic, social and environmental dimensions of a city. The merged framework (Fig. 1) presents the indicators that were used to assess the nexus between urban agricultural and sustainable cities. Overlaps were addressed by taking only one indicator. This however underscores the strength of the indicators in question.

3 Methods

The study is based on a systematic review of secondary data. The term secondary data is used in this study to refer to data that are used to address research questions that are different from the ones the original collector sought to answer (Vartanian, 2011). The search for the secondary data was guided by phrases such as: a) urban agricultural practices, b) indicators for the measurement of sustainable cities, c) economic, social and environmental benefits of urban agriculture, and d) negative effects of urban agriculture on the city. At the end of the search, 189 articles/reports/books related to urban agriculture and sustainable cities were used.

The literature on indicators for sustainable cities was screened for commonalities and differences towards building a conceptual framework, which was used to analyse the nexus between urban agriculture and sustainable cities. The conceptual framework was developed from the following models: a) the Green City Index (Supplementary Table 1), b) the Global City Indicators Facility (Supplementary Table 2) and c) Global Compact Cities Circles of Sustainability (Supplementary Table 3). The framework integrates the strengths of each model and together addresses the inherent weaknesses of a single model. The indicators were then categorised into three, namely economic, social and environmental to reflect the concept of sustainable development (Fig. 3.1). The three dimensions are referred to as themes in this article. The literature was analysed by subjecting each of the content analysed to the specific indicators under the sustainable city themes.

The literature was drawn from several geographical locations with different agro-climatic, economic, social and environmental characteristics. Lessons from these places underscore the importance of urban agriculture to the sustainable city discourse. For instance, in the global north, the importance of urban agriculture is more environmental in nature than socio-economic. However, the social and economic functions of urban agriculture are more

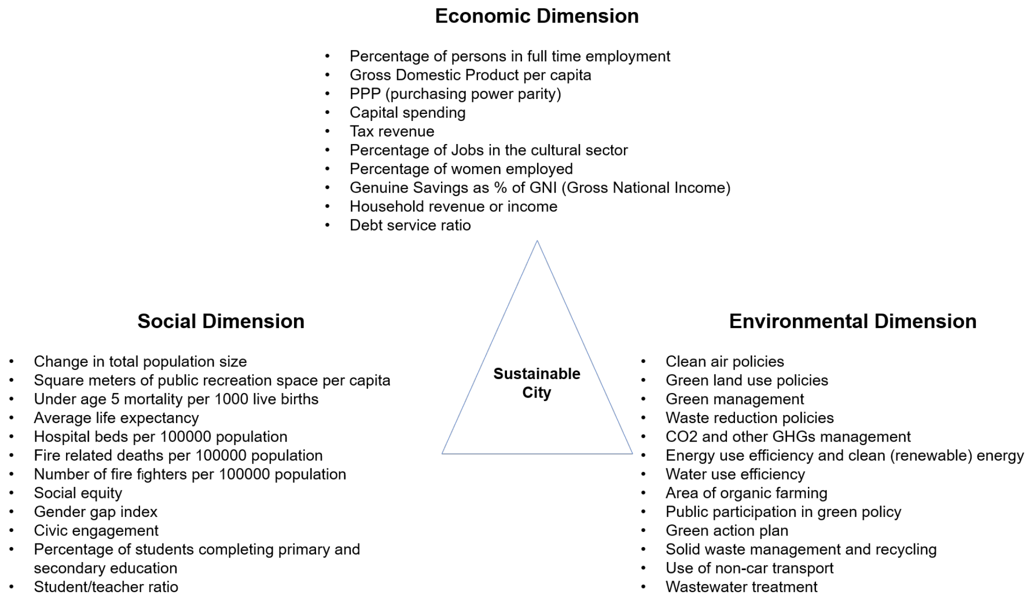

FIGURE 3.1: Sustainable City Framework.

pronounced in the cities in the global south. Despite these differences, the conceptual framework in the present study brings together economic, social and ecological indicators and can be applied in every city. The selection of the crops to cultivate to achieve the sustainability goals would however be based on the local climatic conditions.

4 Analyses

As presented in Fig. 3.1, the indicators for measuring a sustainable city are categorised into economic, social and environmental. This section of the paper discusses the nexus between urban agriculture and sustainable cities with reference to the indicator-sets under each of the themes.

4.1 Urban agriculture and economic sustainability of cities

4.1.1 Full-time employment

Urban agriculture provides employment, and has thus become a major means of livelihood, for people in many cities particularly in the global south (Darkey et al., 2014; Zezza & Tasciotti, 2010). An estimated 2100 farm labourers in Morogoro and 6400 in Mbeya, Tanzania are engaged in urban agriculture as either attendants or fodder collectors (International Labour Organization, 2013). Similarly, approximately 120,000 low-income households (including farmers, garland makers and garland sellers) in Manila, Philippines depend on jasmine production for their livelihoods (IPC, 2007). Many examples of urban agriculture's role in employment creation abound in the conventional literature (see: Amponsah et al., 2015a; Carr, Potter, & Nortcliff, 2011; Sinclair, 2010; Tiongco, Narrod, & Bidwell, 2010). The general observation is that urban agriculture's role in employment creation is widespread in the global south as depicted in Table 4.1.

Not only is urban agriculture a source of employment to farmers but also to stakeholders along the value chain (Fig. 4.1). Community and farmers' markets and door-to-door delivery of food baskets in Argentina, Brazil and Uruguay are examples of jobs created in the commercial sector by urban agriculture (International Labour Organization, 2013). Similarly, majority of vegetable farmers in urban and peri-urban Ghana deliver their produce to wholesalers, who are predominately women, at the farm-gate (Abaidoo et al., 2009; Amoah, Drechsel, Henseler, & Abaidoo, 2007; Amponsah et al.,

TABLE 4.1: Number of people engaged in urban agriculture in the global south. Source: FAO (2007).

Region	Number (million)	Principal live-hood
Sub-Saharan Africa	11	Commercial vegetable growing or dairy farming
Northern Africa and the Middle East region	6	Horticultural and livestock products (fruit, vegetables and poultry)
South Asia	11	Perishable high-value commodities such as milk and fresh vegetables
East and South-East Asia	7	Perishable high-value commodities such as milk and fresh vegetables

2016). These wholesalers in turn sell the produce to retailers, food vendors and households as depicted in Fig. 4.1. The farm produce is conveyed from the farm-gate to the open markets by transport operators.

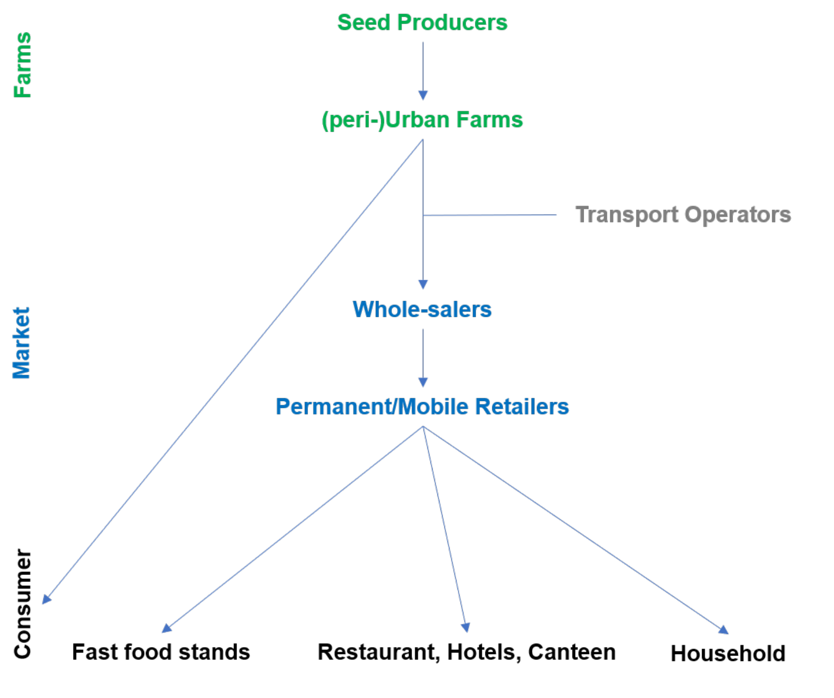

FIGURE 4.1: Fabrication process of carbon nano-wires to achieve through the proposed dissertation.

The discussion so far suggests that urban agriculture makes a profound contribution to the employment of the labour force in the global south. The situation differs from the cities in the global north because the narrative in the conventional literature suggests that the motivation for urbanites and city authorities to promote agriculture in these cities lies in its ecological functions as well as its support for leisure and recreation (Pearson et al., 2010). The implication is that the role of urban agriculture in employment creation in the global north may not be as profound as it is in the global south. This is because, urban agriculture in the global north is not economically-centred but rather centred on its environmental functions. Nonetheless, recent studies give indications that the functions of urban agriculture in the global north is gradually shifting from leisure and recreation to more of urban sustainability and economic resilience (Lovell, 2010; McClintock, 2010). The increasing focus on economic resilience means that the contribution of urban agriculture in the global south and north appears to be converging even though there are variations across cities. Nevertheless, if the agricultural lands had been used for non-agricultural purposes, the employment effects may have been more profound. For instance, industrial and commercial activities on these parcels of land may have made more profound contributions to employment creation.

4.1.2 Employment for women

According to Prain and Lee-Smith (2010), two out of every three urban farmers in Yaounde, Nakuri, Maputo, Nairobi and Kampala are women. Generally, these women farmers engage in subsistence farming with the objective of meeting the family demand for fresh, nutritious and chemical-free food (Gamhewage, Sivashankar, Mahaliyanaarachchi, Wijeratne, & Hettiarachchi, 2015). The rest of the urban women farmers sell the excess produce for income. However, agriculture could be a burden to these women due to the numerous roles they perform at the household level. The argument does not pertain to agriculture but also applies to almost all the economic activities the women are engaged in. The implication is that without addressing the issues that foster gender inequality, women's engagement in agriculture in the cities could be a burden (Veenhuizen, 2006). There must therefore be a conscious effort by policy makers and social advocates to help minimise the pressure on women emanating from the combination of household chores and economic activities such their involvement in urban agriculture.

Generally, commercial urban agriculture is dominated by men as depicted in Table 4.2. In contrast, women are dominant at the market and food vending stages of the supply chain (Drechsel & Keraita, 2014). It can therefore be deduced that commercial agriculture in the cities in the global south is gendered and thus makes a profound contribution to employment for both women and men. However, as the economic arguments have always been, if the agricultural lands were used for nonagricultural purposes, more women may have been employed. This argument lies at the heart of the theory of 'highest and best use' of urban land.

TABLE 4.2: Gender in urban agriculture in selected cities. Source: Drechsel et al. (2006).

Country	City	Female (%)	Male (%)
Benin	Cotonou	25	75
Burkina Faso	Ouagadougou	38	62
Cameroun	Yaoundé	16	84
Cote d'Ivoire	Abidjan/Bouake	5-40	60-95
Gambia	Banjul	90	10
Ghana	Accra, Kumasi, Takoradi and Tamale	10-20	80-90
Guinea	Conakry, Timbi-Madina	70	30
Mali	Bamako	24	76
Mauritania	Nouakchott	15	85
Nigeria	Lagos/Ibadan	5-25	75-95
Sierra Leone	Freetown	80-90	10-20
Togo	Tsévié, Lome	20-30	70-80
India	Delhi, Mumbai, Chennai, Hyderabad and Bengaluru	17	83

4.1.3 Income generation and gross domestic product

Several households in both developing and middle income countries opt for urban agriculture as a source of livelihood (Abaidoo et al., 2009; Foeken & Owuor, 2008; Raschid-Sally & Jayakody, 2008a). Drechsel and Keraita (2014) point out that two out of every three urban vegetable farmers in Accra, Ghana had no intentions of leaving the job even if they were offered regular salaried employment. Based on this and many other factors (such as limited employment opportunities in the formal sectors, flexibility in work schedules, etc.), Amponsah et al. (2015b) conclude that vegetable farming in Kumasi, Ghana's second largest city, had become an employment destination for many.

Amponsah et al. (2015b) conclusion could be attributed to the higher incomes the farmers earned from the agricultural activities in the cities. For instance, Keraita, Jiménez, & Drechsel (2008) identified that urban farmers in Ghana earned twice or more the incomes of their counterparts in rural areas. This appears to be the case in several other cities in the global south as indicated in Table 4.3. The earnings enable the urban farmers to contribute to national income. For instance, YiZhang and Zhangen (2000) found that 2.7 million urban farmers contributed 2% of Shanghai's gross domestic product. Similarly, para grass production and sale in Hyderabad, India contributes an estimated annual income of USD 4.5 million to the city's economy. In Hartford, USA, urban agriculture is estimated to contribute between 4 and 10 million dollars in gross domestic product (Nugent, 1999).

TABLE 4.3: Incomes earned by urban vegetable farmers in six cities. Source: Ensink et al. (2004); Buechler & Devi (2005); Drechsel et al. (2006); Keraita, Jiménez, & Drechsel, 2008.

City	Annual income per ha (US$)	Annual GNI per capita (US$)
Nairobi in Kenya	1770	645
Dakar in Senegal	2234	773
Kumasi in Ghana	420-1920	522
Hyderebad in India	830-2800	771
Haroonabad in Pakistan	840	931
Guanajuato in Mexico	1935	7755

The value of urban agriculture to a city's gross domestic product may not be significant when compared to non-agricultural land uses. This could be a justification for the pricing out of agriculture in city land use planning processes. However, as indicated earlier, gross domestic production and other economic indicators underestimate the actual contribution of urban agriculture to city development. The approach excludes ecological and social dimensions of urban agriculture. Probably, if these dimensions could be valued and added to the value of urban agriculture, then urban agriculture could be as valuable as other land uses.

4.1.4 Savings and expenditure

A study by Prain and Lee-Smith (2010) revealed that households who consumed the produce from their farms in Kampala in Uganda and Yaounde in Cameroon were able to save part of their incomes. Once individuals farm on their own, there is no need to spend money to buy some agricultural commodities. On this basis, Smit, Nasr, & Ratta (2001) maintains that households who engaged in farming in cities in Zambia saved between 10 and 15% of food costs. Furthermore, studies in Bangalore, Nairobi, Lima and Accra revealed that savings coming from own food production enabled households to purchase other types of food (World Bank, 2013). For instance, households in Bangalore were able to save between 1.30 and 80.00 USD per month (World Bank, 2013) whereas farmers in the cities in Kenya were able to save between 7 and 14 USD per month (Freeman, 1993). These savings are spent on other household items that contribute to improved quality of life.

It can be observed from Table 4.4 that expenditure on food in Bangalore, Accra and Nairobi for households who engaged in urban agriculture was below the average of 50–70% for the urban poor (FAO, 2007). The situation in the cities in the global north may be different given that urban households are driven by leisure and recreation to engage in agriculture cites. In these cities, households spend minimum proportions of their incomes on food, which implies limited contribution of urban agriculture to household savings. The savings may however originate from transportation. The literature indicates that households spend less on transport to obtain or transport food as compared to the other household items. Hamilton et al. (2013) had earlier observed that savings occurred as a result of the reduction in transport cost for the urban farmer. The savings result from the amount these farmers would have otherwise incurred if they were to travel to procure the items, they produce themselves. Furthermore, urban agriculture means some farm produce are now closer to consumers than if the produce were to be supplied by rural farmers. This will therefore reduce travel cost and time to access food items by urban dwellers.

TABLE 4.4: Expenditure pattern of urban agriculture households in some selected cities. Source: World Bank (2013).

Expenditure item	Selected cities		
	Bangalore	Accra	Nairobi
Food	29.2	36.5	39.4
Utilities	16.8	12.3	13.1
Education	11.5	16.7	16.9
Health	10.4	8.2	5.1
Clothes	8.1	7.7	3.0
Shelter	7.0	3.2	18.9
Loan/debt	6.2	1.4	0.4
Transport	4.6	7.9	2.5
Other	3.3	0.8	0.2
Family events	2.1	4.5	0.2
Domestic help	0.7	0.8	0.2

4.1.5 Tax revenue

Taxes are very important elements in managing developmental activities in cities. Taxes collected through urban agriculture covers all the actors along the produce supply chain. It is worth noting that, national income from taxes from urban agriculture can be directly linked to the expenditure farmers make and the employment obtained.

Property taxes have been identified as a city's main source of income (World Bank, 2015). Urban agriculture contributes significantly to tax revenues from property taxes. According to Liu (2008) and Voicu and Been (2008), urban farms and community gardens contribute to the increase in home values. For instance, the presence of gardens in California contributed to the rise in property values as much as 9.4

Transportation taxes are also paid by urban farmers who transport their goods within or outside the urban area. Some urban farmers indirectly pay transportation taxes through the purchase of fuel for irrigation or the transportation of farm goods and services. Additionally, the wholesalers or retailers engaged in the sale of the urban agricultural produce pay taxes to city authorities. In Kumasi, a city in Ghana, wholesalers and retailers who operate in the open markets pay taxes in the form of market tolls (tickets) (Baah-Ennumh & Adom-Asamoah, 2012). The amounts paid ranges from 5 to 10GHp (0.01 USD–0.02 USD) a day and are paid to the Kumasi Metropolitan Assembly. Similarly, in the United States, the income that is obtained from urban farming does not represent a separate kind of income. They are determined and taxed like income from other businesses of a comparable size apart from some detailed regulations regarding farm income. However, national subsidies for soil, groundwater or environmental protection, care for wild animals or forests are sometimes tax-free for the farmers (Andersen, Asheim, Mittenzwei, & Veggeland, 2002). In a similar vein, some municipalities (Rosario in Argentina and Cagayan de Oro in The Philippines) use tax exemptions as a means of promoting urban agriculture.

Useful as the taxes may be, taxes to the cities may be more if the agricultural lands had been used for non-agricultural purposes such as commerce or industry. The tax exemptions could also be avoided if the lands were used for non-agricultural purposes. Such arguments are underpinned by the theory of 'highest and best use' which focuses on only the direct economic benefits derived from the use of land. These theories suggest that allocating land for urban agriculture deprives its access for other more economically beneficial uses such as industrial, commercial and residential uses. This explains why a rise in the value of urban agricultural land is mostly associated with the change in use from agriculture to alternative land uses (Nugent, 2000).

4.2 Urban agriculture and social sustainability of cities

4.2.1 Educational functions

Golden (2013) suggests that urban agriculture provides a medium for learning experiences, youth development and educational programmes. Agricultural projects in California and Philadelphia in the United States of America are used to highlight the role of urban agriculture in education (Bradley & Galt, 2014; Ober Allen, Alaimo, Elam, & Perry, 2008; Travaline & Hunold, 2010). These educational services are directed towards teaching the citizens where, how and by whom the food they eat is grown so as to enable them make informed decisions about their food systems. The agricultural projects in the cities serve as avenues for children and adults to acquire practical skills on food production and processing.

Furthermore, through their social networks, urban farmers who have had the benefits of education by research institutions impart the knowledge to their counterparts. For instance, urban vegetable farmers in Kumasi in Ghana who have participated in research activities on the World Health Organization's Multiple Barrier Interventions have transferred the knowledge to their counterparts who were not part of the training programme (Amponsah, Vigre, Schou, Braimah, & Abaidoo, 2015a). This is used to highlight the replication effects of such research projects on the larger community.

Urban farmers' earnings from agriculture are used to support their children in school (Prain & Lee-Smith, 2010). A study conducted in SriLanka by Gamhewage et al. (2015) concluded that 22% of urban farmers prefer to expend their savings on the education of their children to spending on household possessions. Similarly, in India, some women contribute approximately 23% of their share in household education expenditure from the incomes they earn from urban agricultural activities. Another study in Kampala, Uganda also concluded that urban male farmers and female farmers spend 26% and

12% of their incomes respectively on the fees of their wards in school (Devi & Buechler, 2009).

Nevertheless, urban agriculture, particularly in the global south, is known to fuel child labour and truancy in school (Edet & Etim, 2013; International Labour Organization, 2006). For instance, in Dar es Salaam, Tanzania, children have been found to engage in urban agriculture at the expense of their education. Similarly, child migrants have been found to be engaged as farm labourers on urban farms in Kumasi, Ghana (Amponsah et al., 2016). Yet, in these countries, child labour is prohibited. The higher returns from the urban agricultural activities could be an explanation for their attractiveness to children, especially migrant children.

By enforcing the child labour laws, the children can take advantage of the free and compulsory universal primary educational policies and programmes in these countries to enrol in schools (Nishimura & Yamano, 2013; Rodeghier, Hall, & Useem, 1991). This will ultimately enhance the educational functions of urban agriculture towards social sustainability of cities.

4.2.2 Civic engagement

A growing body of literature points to the increasing importance of community supported agriculture in civic engagements. For instance, Obach and Tobin (2014) and Pole and Gray (2013) found that people in New York City who were engaged in urban agriculture were more politically engaged and more likely to volunteer in their communities compared to the general population. Similarly, in Dar es Salaam in Tanzania, urban farms were used as political gathering spaces in the run up to the 2010 elections. In fact, some farms had small concrete platforms that were used for political rallies. Despite these observations, Pole and Gray (2013) maintain that generally, the desire for organic foods is the motivation for people to interact with urban farmers other than civic engagement. Obach and Tobin (2014) add that consumers of urban agricultural produce are less likely to engage in charitable giving than the general population. The authors conclude that if the motivation for engaging in urban agriculture is economic, then it is less likely to promote civic engagement.

The narrative points out that economic reasons including household food security, employment and income generation are the main motivations for people's engagement in urban agriculture (Abaidoo et al., 2009; Amoah et al., 2007; Amponsah et al., 2016; Darkey et al., 2014; International Labour Organization, 2013; Zezza & Tasciotti, 2010). On the other hand, the reasons for agriculture in the cities in the global north are more inclined towards leisure and ecological functions (Hamilton et al., 2013; International Labour Organization, 2013; Walker, 2015). In this regard, urban agriculture's role in civic engagement may be more pronounced in the global north than the global south.

4.2.3 Safety and security

Urban agriculture makes an important contribution to the safety of a city. For instance, roof-top gardens help to promote energy efficiency in buildings and contribute to fire prevention (Hoornweg & Munro-Faure, 2012; Rashid & Ahmed, 2011; Wong et al., 2003). Furthermore, clearing an area of bush in a city for agricultural purposes has the potential to eliminate hiding spaces for thieves (real or imagined). Customers, people walking through, people who live nearby, people looking for a day labour job, and more, all interact with urban farmers. The interactions make profound contributions to the social sustainability of cities.

A study by the University of Pennsylvania's Perelman School of Medicine in Philadelphia found that greening vacant lots (which could take the form of urban agriculture) made nearby residents feel significantly safer, and that the greened lots were linked to reductions in certain gun crimes in the area (Krauser, 2012). This is consistent with the results of the work of Kuo and Sullivan (2001) which revealed that the greener a building's surroundings were, the fewer the reported crimes. Following this, the Youngstown Neighbourhood Development Corporation initiated a 'Lots of Green' programme in 2010 to reuse vacant lands. A recent study established that there were reductions in burglaries around stabilisation lots, and assaults around community reuse lots (Kondo, Hohl, Han, & Branas, 2016). This could be a validation of the broken window theory, which states that maintaining and monitoring urban environments in a well-ordered condition may stop further vandalism and escalation into more serious crime. The Urban Food Crisis (2018) explains that using blighted lots for urban agricultural purposes sends a signal that criminal activities are not welcome in the area, which ultimately reduces crime rates.

Other studies point to the negative side of urban green space (Bixler & Floyd, 1997; Ulrich, 1993; Van den Berg & Ter Heijne, 2005). These include encounters with physical danger such as poisonous animals and thorny plants, and the fear of crime (Sreetheran & van den Bosch, 2014). These authors, after a systematic review of literature, point out, however, that factors such as gender and individual's experiences are most influential in evoking fear of crime. This means that the crimes that result from urban agriculture may be imagined from an earlier experience. A fear of crime may therefore be imagined but not real. People should be alerted to thorny plants and poisonous animals to mitigate the adverse effects on neighbourhoods. These measures could enhance the role of urban agriculture in urban safety and security.

4.2.4 Gender equality and social equity

Urban agriculture contributes to bridging gender gap and promotes social equity through the employment opportunities it offers to both men and women. As presented earlier in Table 2, women form a significant part of the labour force that is engaged in urban agriculture. They can gain employment at every stage of the supply chain. This reduces gender inequalities (Eigenbrod & Gruda, 2015; International Labour Organization, 2013). A study conducted in Kisumu in Kenya by Mireri (2013), concluded that the proportion of male family labour engaged in urban agriculture is slightly higher (53%) than that of women. However in the case of hired labour, more women (54%) than men were employed. Kutiwa, Boon, and Devuyst (2010) also point out that urban agriculture in Harare in Zimbabwe provides women the opportunity to earn secondary income, improve nutritional value of the household diets, and participate actively in budgeting and decisionmaking processes at the household level. Similarly, both men and women are engaged in mushroom production, horticulture, aquaculture and livestock farming in Accra in Ghana (World Bank, 2013). These cases reveal that urban agriculture contributes to bridging the gender gap, which has positive implications for social equity.

However, women tend to engage in urban agriculture for household food supply while men engage in it for economic reasons. This could perpetuate the income gap between men and women in many cities. Furthermore, the disparity in the gender roles at the family level implies greater burden on women in the cities in the global south than men. Typically women shoulder more household responsibilities (like childcare and domestic work) than men

(Lachance-Grzela & Bouchard, 2010; Mencarini & Sironi, 2012), which implies that urban agriculture could have the potential to aggravate the burden of work on women and gender inequality (Veenhuizen, 2006). These have implications for the systems and practices that perpetuate gender inequality but not necessarily preventing a certain gender category from engaging in urban agricultural activities or any economic activities.

4.2.5 Health benefits

Urban agriculture contributes to the health of a city through its contribution to food security (Golden, 2013; Opitz et al., 2016; Twiss et al., 2003; World Bank, 2013) and income for farmers and their families to access health care. Community gardens give residents access to fresh fruits and vegetables (Larsen & Gilliland, 2009; Park et al., 2011), which are critical to safeguarding their health and that of the city in general. From a social point of view, urban agriculture can ensure food availability and accessibility, which can translate into food affordability. Also, women take advantage of the produce from household gardens to diversify the family food intake, which ultimately results in healthier diets. Research also shows that people who participate or have family members that engage in community gardens "were 3.5 times more likely to consume fruits and vegetables at least 5 times per day than people without a gardening household member" (Alaimo, Packnett, Miles, & Kruger, 2008). In this regard, urban agriculture helps to reduce malnutrition and promote the general health of the city population.

However, some studies point to the adverse effects of urban agriculture on the health of the cities. These studies highlight the excessive use of agrochemicals (Obuobie et al., 2006; Veenhuizen, 2006; Yamusa, 2014), which could undermine the health of producers, consumers and environment at large, and the use of untreated wastewater for food production without regard to safe practices in many cities in the global south (Amponsah, Vigre, Schou, Braimah, & Abaidoo, 2015a; Becerra-Castro et al., 2015; Mara & Sleigh, 2010; Ndunda & Mungatana, 2013; Veenhuizen, 2006). In addition, the urban agricultural farms can result in the spread of diseases through mosquitoes and the scavenging animals.

Based on these adverse effects, the emphasis of the discourse on the role of urban agriculture in cities' social sustainability should focus on responsible agriculture. This underscores the need to regulate the urban agricultural subsector for compliance with safe agricultural practices and general neighbourhood sanitation measures.

4.2.6 Recreation

Community gardens and rooftop gardens contribute to both indoor and outdoor recreation (see Hamilton et al., 2013; Walker, 2015). These gardens can provide a place where people in an area in a city come together for mutual benefits. For instance, in the early 20th Century, upper class Russians resorted to dachas as hobby farming to improve upon recreation (Hamilton et al., 2013). Community gardens and rooftop garden also serve as tourist attraction centres (International Labour Organization, 2013) and improve the value of urban property. A classic example of this is in Beijing China. Here, people spend one-day to tour over 1900 sightseeing farms and pick produce (International Labour Organization, 2013).

Some individuals in Detroit have resorted to urban agriculture as a means of increasing the value of their property (Walker, 2015). Each community garden in California also contributed about half a million dollars to the local economy through rise in the value of real property (Voicu & Been, 2008). People are attracted to some of these buildings because of the plants and ornaments around. It is on the basis of this that the World Bank (2013) suggest that countries should consider integrating urban agriculture into urban greening as a means to improving recreation, aesthetics and property values in their cities.

4.2.7 Technology and innovation promotion

Urban agriculture provides the avenue for the development of technology. For instance, some urban farms in Hong Kong Island, China are recycling water with PV-powered UV-LED disinfection (Close, Ip, & Lam, 2006). Other farms use hydroponic (Buehler & Junge, 2016; VOA News, 2016; Woodford, 2018), film farming (Joe, 2017) and aeroponic (Vyawahare, 2016) systems to produce leafy greens, tomatoes, and herbs. These technologies could contribute to the preservation of urban agriculture and its significant roles even in cities where land is increasingly becoming scarce due to rapid urbanisation.

Urban agriculture also provides an avenue for new research and technology to be developed. Examples include research on varieties of seeds, and type and amount of light required for plant growth. This type of agriculture therefore incorporates the use of technology as a means of optimising levels of production. Disregarding technology and innovation in urban agriculture could result in unreliable and ineffective farms.

4.3 Urban agriculture and environmental sustainability of cities

4.3.1 Management of emissions

Cities are noted for their poor air quality due to emission from vehicles and industries (Chen, Guo, Shao, Li, & Chen, 2013; Heather, 2012). The cities are often found to have dangerous levels of greenhouse gases. Urban agriculture can play significant roles in the management of these emissions (Padgham, Jabbour, & Dietrich, 2015). It is estimated that 711,000 metric tons of air pollution is removed annually by urban trees (Yang, Yu, & Gong, 2008). However, in densely populated urban areas, it is almost always impossible to plant enough trees to promote air quality. In such situations, rooftop gardens can be encouraged although this has cost implications because of the need for buildings with supportive structural integrity.

Yang et al. (2008) found that the levels of acidic gaseous chemicals and particulate matter decreased by 37% and 6%, respectively, on a 4000 m_2 green roof built in Singapore. Similarly, a Toronto study estimated that 7.87 metric tons of air pollutants per year could be removed by 109 ha of green roofs (Yang et al., 2008). In this regard, planners, particularly in the cities in the global north, are making conscious efforts to mainstream green infrastructure in city land use planning. For instance, the government of Canada under the Ottawa Green Belt Programme has acquired 37,000 acres of land and leased these lands for green infrastructural purposes, which includes farming (Pearson et al., 2010; Whyte, 2002). However, the cost implications make roof-top gardening in the cities in the global south difficult to adopt. Zoning and planning regulations in these cities should rather integrate urban agriculture into city land use systems rather than taking reactionary measures like roof-top gardening.

Despite the ability of urban agriculture to manage emissions, some studies have argued that organic urban agriculture can result in the emission of some gases, which may be detrimental to the environment. According to Davison and Cape (2003), about 90% of atmospheric ammonia in the US come from organic agriculture. The ammonia originates from agricultural activities including soils, fertilisers and domesticated animals waste (Paulot et al., 2014; Van Damme et al., 2014). The ammonia compound (gas-to-particle or acidic reactions), is transported by winds and returns to the surface by wet or dry processes, which may contribute to the degradation of air quality and visibility, as well as to the atmospheric radiative balance (Aneja, Schlesinger, & Aneja, 2015; Wang et al., 2015). To guarantee urban agriculture's role in the management of emissions, there ought to be stringent monitoring and reduction of the dietary crude protein for animals to reduce ammonia in animal waste. Again, chemicals such as aluminium sulphate (alum), ferrous sulphate, phosphoric acid, and proprietary products can be used to acidify ammonia in animal waste making it non-volatile (Powers, 2002).

4.3.2 Water management

Sustainable water management has been the aim of city authorities across the globe. This is because forecasts by the OECD (2012) suggest that over 40% of the world's population will live in water-stressed regions of the world by 2050. It is estimated that irrigated agriculture accounts for around 70% of all the world's freshwater withdrawals (Rosegrant, Ringler, & Zhu, 2009). The implication is that irrigated urban agriculture can exacerbate the pressure on available freshwater resources particularly in the water-stressed regions of the world. Therefore, the dilemma is whether to promote urban agriculture and risk exacerbating the pressure on freshwater resources or apply the limited freshwater for non-agricultural purposes and forego its roles in the sustainability of cities. Strategies that can mitigate the effects of irrigated urban agriculture on sustainable water management could be the antidote to the dilemma.

The conventional literature indicates that strategies such as wastewater reuse, sheet mulching, swales and basins, and drip irrigation can reduce the pressure urban agriculture poses on freshwater resources (Ensink, Hoek, Matsuno, Munir, & Aslam, 2002; Kretschmer, Ribbe, & Gaese, 2010; Nolasco, 2011; Post, 2006). Similarly, technologies such as aeroponics, film farming (Ayambire, Amponsah, Peprah, & Takyi, 2019; Richman, 2015; Vyawahare, 2016), automated weather station networks, soil and plant measurement systems, and dynamic simulation models (Itzhaky, Koppel, & Shpiz, 2017; Malano

& van Hofwegen, 2018; Phene, 1989) can alleviate water scarcity challenges. The prohibitive cost of these technologies undermines their adoption for agricultural purposes particularly in cities in the global south where incomes are low (Ayambire et al., 2019). Their use for micro-scale production, which is typical of urban agriculture, makes its use uneconomical. The discussion points to the use of less costly options such as sheet mulching and wastewater for restricted irrigation.

Wastewater treatment is ideal. However, the high wastewater treatment cost challenges its adoption in the low-income cities in the global south. In this regard, emphasis of the discourse should be on wastewater reuse for restricted irrigation (Hamilton et al., 2007; Pedrero, Kalavrouziotis, Alarcón, Koukoulakis, & Asano, 2010; RaschidSally & Jayakody, 2008b), which calls for its promotion to resolve the negative perceptions urbanites have about wastewater reuse for productive purposes (Mayilla, Keraita, Ngowi, Konradsen, & Magayane, 2015; Owusu et al., 2012). Urban farmers and stakeholders along the value-chain should also be monitored to comply with health risks reduction measures (see WHO guidelines for the safe use of wastewater, excreta and greywater in agriculture) when using wastewater for restricted irrigation purposes. This will safeguard public health. Land tenure security could be an important strategy to encourage the commercial urban farmers, particularly in sub-Saharan Africa, to comply with the health risks reduction measures.

4.3.3 Waste management

Urban agriculture provides a means by which municipal organic waste is put to good use. Due to its nutrient-rich character, Germany encourages the use of solid waste as compost in agriculture. Other European Union member states are developing ideas and techniques to collect organic waste and produce compost for agriculture (Anastasiou et al., 2014). A study in New York City in 2009 reported that more than 130 community gardens had composting activities, which were integrated with the existing city sanitation policy and plans. Similarly, the municipality of Governador Valadares provides incentives for composting and reuse of household wastes in urban farms. The City of Cape Town also provides incentives for the use of compost by poor urban farmers (Hoornweg & Munro-Faure, 2012). The use of compost for crop farming in the cities in the global south has been extensively reported in the conventional literature (Hassan, Farouk, & Abdul-Ghani, 2012; Jiménez et al., 2010; Keraita, 2008; Seidu, Heistad, Amoah, Drechsel, & Petter, 2008). These initiatives help to improve environmental sanitation.

Urban agriculture also contributes to the treatment of wastewater and ultimately minimises the rift between nature and the environment. Lydecker and Drechsel (2010) estimate that vegetable farms in Accra in Ghana treat the wastewater from about 225,000 households. The soils serve as filters for the treatment of the wastewater that is used for irrigation purposes. However, Drechsel and Keraita (2014) maintain that urban farms can only absorb and filter a limited proportion of the wastewater due to the high degree of pollution in these areas in developing countries. Despite this, agricultural lands play significant roles in reducing the extent of environmental pollution that results from the discharge of untreated wastewater into the environment. Using wastewater for irrigation purposes amounts to internalisation of resources in the cities, which is consistent with the concept of sustainable cities. Pollution of the sea and other freshwater resources by untreated wastewater is reduced when it is encouraged for irrigation purposes (Liu & Persson, 2013).

Despite the promising role of urban agriculture in urban waste management, urban agriculture can lead to the discharge of wastewater into water bodies. According to Veenhuizen (2006), urban poultry farms as well as farms that use poultry manure may discharge wastewater high in micro-organisms into open water supplies. As a mitigating strategy, some cities (such as Harare in Zimbabwe) have adopted an approach to filter water from farms through a natural purification process before it enters the city reservoir (Toriro, 2003). The emphasis of the discourse should, therefore, be safe and responsible urban agriculture to offset its adverse effects on city waste management

4.3.4 Energy efficiency

Cities tend to be warmer than their surroundings as a result of the high energy consumption (Heather, 2012). Urban heat island effects cause cities to have daytime surface temperatures of up to 10 °C higher than the suburban and rural areas around them (Voiland, 2010). Urban agriculture can help to reduce the urban heat island effects by providing shade and enhanced evapotranspiration, and thus providing more cooling and less smog. A study in the University of Manchester revealed that a 10% increase in the amount of green, possibly through urban agriculture in cities, can help to reduce surface temperatures in urban environments by up to 4 °C (Gill, Handley, Ennos, & Pauleit, 2007). A similar study in New York City showed that a combination of urban forests and white roofs can reduce overall daytime temperatures by 1.2 F, and by 1.6 F around the peak temperature time of 3 pm (Scott, 2006).

Shading by vegetation blocks help to redistribute incoming solar radiation and diffuses light reflected from nearby urban surfaces (Akbari, 2002; Alexandri & Jones, 2008) that would otherwise be reflected or re-radiated as sensible heat by urban surfaces (Memon, Leung, & Liu, 2008). Green roofs can increase evapotranspiration while reducing the energy demand for space climate conditioning (Guo-yu et al., 2013). Green roofs can also help in the management of energy consumption in residential buildings and its intensity. They can also help decrease the energy required to heat and cool buildings (Ackerman, 2012). The location of farms in cities also reduces the need to transport goods such as food to markets and farm inputs to farms. This helps to manage the energy consumption from the transport sector (World Bank, 2013).

The energy efficient function of urban agriculture suits the proponents of compact cities who are focused on managing energy and pollution. Despite the ability of urban agriculture to manage energy, the intensive use of technology may intensify the energy use in the cities. A study conducted in Yuma, Arizona, USA compared the energy requirements of hydroponics and conventional agriculture. The conclusion was that hydroponics offered 11 ± 1.7 times higher yields but required 82 ± 11 times more energy compared to conventionally produced lettuce (Barbosa et al., 2015). The argument in the discourse therefore points out that though urban agriculture helps to manage energy use in the cities, some technologies have the potential to increase energy use in the city. Focus on renewable energy use by these technologies could help to manage emissions. This should be an area for research.

4.3.5 Organic farming in percentage of total agricultural area

Organic agriculture has received attention in a growing body of literature. Even though agriculture provides food, it is a major contributor to greenhouse gases, biodiversity loss, agro-chemical pollution, and soil degradation (Crowder & Reganold, 2015). This has brought up the debate of adopting alternative farming systems that are more environmentally friendly. In Germany, there have been new developments to heavily promote organic farming and the banning of pesticide use in public owned urban allotment gardens. There are more than 1.4 million organised allotment gardens, which occupy an area of nearly 47,000 ha (Hoornweg & Munro-Faure, 2012).

In New York City, organic farming reduces the environmental and economic costs of dealing with the city's waste stream by using waste as compost. Also, in Rosario in Argentina, organic waste is converted into bio-fertiliser and reused. Similarly, El Alto, Bolivia recycles organic waste material from the gardens to feed and raise guinea pigs (Hoornweg & Munro-Faure, 2012).

The adoption of a labour intensive production in urban agriculture results in the consumption of less crude fuel by machinery for extracting, processing and transporting fossil fuel based fertilisers (Cruse, Liebman, Raman, & Wiedenhoeft, 2010). However, the idea of using waste for compost may escalate into untenable negative effects if not managed well. The odour that may be created from the waste from animals (Hallett et al., 2016) may negatively affect the role of urban agriculture contributing to organic farming. There is the need for regulations to manage the organic substances used in the farmers to mitigate the adverse effects.

5 Discussion

5.1 Urban agriculture-sustainable city nexus

Based on the theory of 'highest and best use' of land, authorities of cities across the globe prefer to zone urban lands for non-agricultural purposes. This is underpinned by the perception that agriculture in cities does not promote the highest and best use of city land due to its low bid-rent. Consequently, agriculture has been priced out of the city landscape, at a period where the clarion call for sustainable cities has been loud. Some scholars maintain that pricing out agriculture from a city landscape undermines its sustainability efforts in terms of economic, social and ecological functions (Ackerman et al., 2014; Binns & Nel, 2013; Dimitri, Oberholtzer, & Pressman, 2016; McLees, 2016; Obach & Tobin, 2014; Opitz et al., 2016; Pole & Gray, 2013; Prain & Lee-Smith, 2010; Specht et al., 2013). Other scholars refute agriculture's role in the sustainability of cities (Edet & Etim, 2013; International Labour Organization, 2006; Obuobie et al., 2006; Veenhuizen, 2006; Yamusa, 2014). To this group of authors, the roles of urban agriculture in sustainable cities have been exaggerated. Some of the agricultural practices even undermine the sustainability efforts of cities while the positive roles are not significant enough to contribute to sustainable cities. Based on the ongoing debate, the purpose of this review paper was to attempt to clarify the nexus between urban agriculture and sustainable cities.

The results of the review indicate that the urban agriculture-sustainable city nexus manifests in economic, social and ecological terms. From the economic perspective, urban agriculture contributes to fulltime employment (including employment for women), income generation, savings, capital spending, and tax revenue. Its unbiased nature, in terms of employment creation and savings for both males and females (Prain & Lee-Smith, 2010), has positive implications for gender equality and social equity. However, these economic benefits, measured in terms of full-time employment, household and city income, and capital spending, could have been higher if the prime lands used for agriculture were used for non-agricultural purposes such as commercial, industrial or residential. For instance, with reference to the Alonso's bid-rent theory, commercial and industrial land uses can offer higher rents for a parcel of land acquired and used for these purposes. Furthermore, non-agricultural land uses in cities may make more profound contributions to employment creation and capital expenditure than urban crop farming despite its labour-intensive character. The high land rent and job creation may have positive implications for a city's income through taxation.

Urban agriculture's roles in food security in cities appear to have been exaggerated (Frayne, Mccordic, & Shilomboleni, 2014). For instance, some scholars (Amponsah et al., 2016; Astee & Kishnani, 2010) claim that this exaggeration is because of vegetables and herbs being the dominant produce from the sub-sector. The narrative in the conventional literature suggests that the calorie content of vegetables and herbs is low (Darmon, Darmon, Maillot, & Drewnowski, 2005) for which reason they are associated with lower risks of chronic diseases (Wadhera, Capaldi Phillips, & Wilkie, 2015). In this regard, the vegetables and herbs can only perform supplementary roles in food security. The discussion, therefore, indicates that urban agriculture loses the debate in the economic sustainability of cities, especially when compared with land uses such as commercial, industrial and residential whose bid-rents are higher. This could explain city authorities' low affinity for agricultural land uses in city landscapes (Nugent, 2000).

However, the economic sustainability analyses are only based on the direct benefits of urban agriculture and disregard its ecological functions. For instance, the waste management functions of urban agriculture not only promote environmental quality but also create employment for those who produce compost from municipal waste for use in the urban farms. Furthermore, the emission management roles of urban agriculture (Chen et al., 2013; Heather, 2012; Padgham et al., 2015; Yang et al., 2008) contribute to making cities liveable. Urban agriculture's roles in sustainable cities are further evident in its profound roles in water management (Richman, 2015; Vyawahare, 2016) and energy-efficiency functions (Gill et al., 2007; Guo-yu et al., 2013; Voiland, 2010).

Karl Marx, in his theory of metabolic rift, argued that "large landed property produces conditions that provoke an irreparable rift in the interdependent process of social metabolism, which is prescribed by the natural laws of life" (Marx, 1981). In this vein, urban agriculture, through its ecological functions, can help to mitigate the adverse effects of commercial, industrial and residential investments on cities physical environment. This underscores the importance of urban agriculture to the sustainability of cities. These environmental functions are not considered in the discourse on the role of urban agriculture in economic sustainability of cities mainly because quantifying the economic benefits of the environmental services appears to be a daunting task. Therefore, the implication is that the conclusions on the role of urban agriculture in the sustainable city discourse appear to be based on incomprehensive analysis of its roles in city sustainability. Researchers must therefore be cautious when using cost-benefit analysis to assess the benefits derived from urban agriculture since it can grossly be under estimated (Takyi & Seidel, 2017).

Its social roles further consolidate its position in the city sustainability discourse. These social roles include education (Bradley & Galt, 2014; Golden, 2013; Ober Allen et al., 2008; Travaline & Hunold, 2010); safety and security (Hoornweg & Munro-Faure, 2012; Krauser, 2012; Rashid & Ahmed, 2011; Wong et al., 2003); human health (Golden, 2013; Opitz et al., 2016; Twiss et al., 2003; World Bank, 2013); recreation (Hamilton et al., 2013; Walker, 2015); and technology and innovation (Buehler & Junge, 2016; Close et al., 2006; Woodford, 2018). However, these roles are seldom quantified and included in the valuation of the benefits of urban agriculture in the sustainable city discourse.

From the discussion, we point out that the discourse on the role of urban agriculture in the sustainability of cities should not focus on only the economic dimension of sustainability but consider the social and environmental dimensions together with the economic benefits. Concluding only on the economic benefits is a travesty of the whole idea of sustainable development.

5.2 Implications for cities in the global south and compact cities

The narrative suggests that the cities in the global south are the worst culprits in pricing out agriculture from the city landscape (see: Cobbinah &

Niminga-Beka, 2017; Kuusaana & Eledi, 2015). The authorities of these cities should make spaces available for urban agriculture. These spaces should be acquired from the owners and be zoned for agricultural purposes. The justification lies in the social and ecological functions of urban agriculture. Furthermore, the riparian areas that are often avoided by developers in developing countries due to their marginal nature and the high cost of their development should be zoned for urban agricultural purposes. For instance, in Ghana, these areas are already in use by urban farmers who produce vegetables for the growing population of vegetable consumers (Amponsah, Vigre, Schou, Braimah, & Abaidoo, 2015a; Orsini, Kahane, Nono-Womdim, & Gianquinto, 2013). Wetland farming is also a major source of livelihood for farmers in Rwanda although that poses several challenges to its ecological functions (Nabahungu & Visser, 2011). However, farming practices that completely change the landscape from the use of inorganic farming practices undermine the ecological functions of the riparian areas. Organic rice farming in these riparian areas could be ideal strategy to sustaining the ecological uses of these riparian areas (Lawler, 2004). Planting commercial trees in these areas can also be an important strategy to cleaning the urban environment. The lands must be acquired by paying the right amount of compensations to the landowners. This will ensure their continued use for agricultural purposes.

Compact cities are much more focused on intensification, consolidation or densification, particularly around inner suburbs (Abdullahi et al., 2015). A shift from land-intensive urban agricultural practices to soil-free and less land intensive agricultural practices could be the ideal pathway to sustaining urban agriculture in these cities. Models such as roof-top gardening, film farming, aeroponic, hydroponic and sack farming would not only sustain urban farming but also ensure water and energy use efficiency as well as guarantee the health of the stakeholders along the value chain due to the limited agro-chemicals (Joe, 2017; Vyawahare, 2016; Woodford, 2018). These farming models do not require soil, hence their suitability for cities that are bedevilled by land scarcity. Film farming, for instance, is practiced across 180 farms in Japan and has been tested in China, Pakistan, Nigeria, and the United Kingdom. Sack farming has also been successful in Kenya, Uganda, Bangladesh (Peprah, Amoah, & Akongbangre, 2014). The implication of the study is that the city land use planning process and building permitting process in developing countries need to be reviewed to accommodate these models of urban agricultural practices.

6 Conclusion

The complexities involved in the development of sustainable cities cannot be overlooked by researchers and policy makers. The concept of sustainability has over the years been over-simplified. This has led to researchers and policy makers focusing mostly on the multi-functional dimensions of sustainability to the neglect of the complementary and conflicting roles of these functions. This study, which seeks to determine the nexus between urban agriculture and sustainable cities has helped in clarifying the various divergent arguments in the sustainable city discourse. Conceptually, this research relied on a framework that assesses the sustainability of cities from the economic, social and environmental sustainability dimensions. Its strengths lie in the use of a comprehensive set of indicators to measure sustainable cities, which makes the framework relevant to both research and policy making.

The results show that the social, economic and environmental functions of urban agriculture have both positive and negative outcomes. The review further showed that, the benefits of urban agriculture especially the ecological and social dimensions have been grossly underestimated. This has led researchers such as Veenhuizen (2006) and Yamusa (2014) to argue that the contributions of urban agriculture to sustainable cities have been exaggerated. However, the review indicates that urban agriculture can propel the drive of many countries, especially in the Global South, towards sustainable development. Varying contextual factors such as climate, topography, increasing rate of urbanisation, land commodification and scarcity affect the nature of agricultural activities. For instance, vertical farming techniques and container gardens may be appropriate in compact cities where land scarcity is highly prevalent. Similarly, water-efficient technologies and wastewater reuse should be encouraged in cities within the arid and semi-arid regions of the world.

In cities with relatively large vacant lands, urban agriculture should be sustained through conscious integration into city land use planning and zoning processes. In the developed countries where there is effective enforcement of land use regulations, ecologically-sensitive areas can be protected through zoning regulations and can provide spaces for urban farming practices that reinforce their ecological functions. However, in developing countries such as Ghana where there is ineffective enforcement of land use regulations, urban agriculture could play an important role in helping to protect these ecologically sensitive areas. Ecologically sensitive areas such as wetlands play very significant functions in the city such as flood management. We therefore suggest that zoning these areas which are already in use for urban agriculture could serve a dual function of protecting them as well as sustaining urban agriculture. Emphasis is on responsible agriculture, which will largely protect the ecological functions of these land uses. Urban green spaces and ecologically-sensitive areas that will be zoned for agricultural purposes must be acquired by the government and city authorities by paying the right amount of compensations to the land owners. This will help to address the problem of land commodification by traditional authorities and other land owners.

The general conclusion is that the nature of agriculture in the cities should be informed by the unique characteristics of that city. Agriculture should be sustained in the landscape of these cities due to its profound roles in the sustainable-city discourse.

References

[1] Ramazan Ali Abuzade, Ali Zadhoush, and Ali Akbar Gharehaghaji. "Air permeability of electrospun polyacrylonitrile nanoweb". In: *Journal of Applied Polymer Science* 1.126 (2012). DOI: 10.1002/app.36774. URL: https://www.researchgate.net/publication/262871690%7B%5C_%7DAir%7B%5C_%7Dpermeability%7B%5C_%7Dof%7B%5C_%7Delectrospun%7B%5C_%7Dpolyacrylonitrile%7B%5C_%7Dnanoweb.

[2] Jan Boer and Clemens Blitterswijk. *Tissue Engineering*. Ed. by Academic Press of Elsevier AP. 2nd. Safary O Reilly, 2014. URL: https://learning.oreilly.com/library/view/tissue-engineering-2nd/9780124201453/XHTML/B9780124201453000109/B9780124201453000109.xhtml.

[3] Braulio Cárdenas. "Advanced Manufacturing Techniques for the Fabrication and Surface Modification of Carbon Nanowires". In: (2017), p. 160.

[4] J. J. Feng. "The stretching of an electrified non-Newtonian jet: A model for electrospinning". In: *Physics of Fluids* 14.11 (Nov. 2002), pp. 3912–3926. ISSN: 1070-6631. DOI: 10.1063/1.1510664. URL: http://aip.scitation.org/doi/10.1063/1.1510664.

[5] Rosalind Elsie Franklin. "Crystallite growth in graphitizing and non-graphitizing carbons". In: *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences* 209.1097 (Oct. 1951), pp. 196–218. ISSN: 2053-9169. DOI: 10.1098/rspa.1951.0197. URL: http://www.royalsocietypublishing.org/doi/10.1098/rspa.1951.0197.

[6] Pankaj Gupta. "Processing-Structure-Property Studies of: I) Submicron Polymeric Fibers Produced By Electrospinning and II) Films Of Linear Low Density Polyethylenes As Influenced By The Short Chain Branch Length In Copolymers Of Ethylene/1-Butene, Ethylene/1-Hexene &amp". In: (Dec. 2004). URL: https://vtechworks.lib.vt.edu/handle/10919/30090.

[7] Ji-Huan He et al. "Mathematical models for continuous electrospun nanofibers and electrospun nanoporous microspheres". In: *Polymer International* 56.11 (Nov. 2007), pp. 1323–1329. ISSN: 09598103. DOI: 10.1002/pi.2370. URL: http://doi.wiley.com/10.1002/pi.2370.

[8] Matthew E. Helgeson et al. "Theory and kinematic measurements of the mechanics of stable electrospun polymer jets". In: *Polymer* 49.12 (June 2008), pp. 2924–

2936. ISSN: 0032-3861. DOI: 10.1016/J.POLYMER.2008.04.025. URL: https://www.sciencedirect.com/science/article/pii/S0032386108003522.

[9] E J Hinch. *Lecture 2: Constitutive Relations*. Tech. rep. URL: https://www.whoi.edu/cms/files/lecture02%7B%5C_%7D28326.pdf.

[10] Moses M Hohman et al. "Electrospinning and electrically forced jets. II. Applications". In: (2001). DOI: 10.1063/1.1384013. URL: http://pof.aip.org/pof/copyright.jsp.

[11] Kolin C Hribar et al. "Light-assisted direct-write of 3D functional biomaterials." In: *Lab on a chip* 14.2 (Jan. 2014), pp. 268–75. ISSN: 1473-0189. DOI: 10.1039/c3lc50634g. URL: http://www.ncbi.nlm.nih.gov/pubmed/24257507.

[12] Nagham Ismail et al. "Simplified modeling of the electrospinning process from the stable jet region to the unstable region for predicting the final nanofiber diameter". In: *Journal of Applied Polymer Science* 133.43 (Nov. 2016). ISSN: 00218995. DOI: 10.1002/app.44112. URL: http://doi.wiley.com/10.1002/app.44112.

[13] Stefan. Landis. *Nano-lithography*. ISTE, 2011, p. 325. ISBN: 9781848212114. URL: https://learning.oreilly.com/library/view/nano-lithography/9781118621707/.

[14] Seungsin Lee and S. Kay Obendorf. "Use of Electrospun Nanofiber Web for Protective Textile Materials as Barriers to Liquid Penetration". In: *Textile Research Journal* 77.9 (Sept. 2007), pp. 696–702. ISSN: 0040-5175. DOI: 10.1177/0040517507080284. URL: http://journals.sagepub.com/doi/10.1177/0040517507080284.

[15] Wallace Woon-Fong Leung, Chi-Ho Hung, and Ping-Tang Yuen. "Effect of face velocity, nanofiber packing density and thickness on filtration performance of filters with nanofibers coated on a substrate". In: *Separation and Purification Technology* 71.1 (Jan. 2010), pp. 30–37. ISSN: 1383-5866. DOI: 10.1016/J.SEPPUR.2009.10.017. URL: https://www.sciencedirect.com/science/article/pii/S1383586609004407.

[16] Marc J. Madou et al. "Controlled Continuous Patterning of Polymeric Nanofibers on Three-Dimensional Substrates Using Low-Voltage Near-Field Electrospinning". In: *Nano Letters* 11.4 (2011), pp. 1831–1837. ISSN: 1530-6984. DOI: 10.1021/nl2006164.

[17] Ismaila Nagham et al. "A mathematical model to predict the effect of electrospinning processing parameters on the morphological characteristic of nanofibrous web and associated filtration efficiency". In: *Journal of Aerosol Science* 113 (Nov. 2017), pp. 227–241. ISSN: 0021-8502. DOI: 10.1016/J.JAEROSCI.2017.08.013. URL: https://0-www-sciencedirect-com.millenium.itesm.mx/science/article/pii/S0021850216302154.

[18] S Rafiei et al. "Cellulose Chemestry and Technology". In: 47 (2013), p. 323. URL: http://www.cellulosechemtechnol.ro/index.php.

[19] Darrell H. Reneker and Hao Fong. "Polymeric Nanofibers: Introduction". In: Feb. 2006, pp. 1–6. DOI: 10.1021/bk-2006-0918.ch001. URL: http://pubs.acs.org/doi/abs/10.1021/bk-2006-0918.ch001.

[20] P C Roozemond and R H M Solberg. *A Model for Electrospinning Viscoelastic Fluids*. Tech. rep. 2007. URL: http://www.mate.tue.nl/mate/pdfs/7892.pdf.

[21] Y. M. Shin et al. "Electrospinning: A whipping fluid jet generates submicron polymer fibers". In: *Applied Physics Letters* 78.8 (Feb. 2001), pp. 1149–1151. ISSN: 0003-6951. DOI: 10.1063/1.1345798. URL: http://aip.scitation.org/doi/10.1063/1.1345798.

[22] M.T.H Siddiqui et al. "Fabrication of advance magnetic carbon nano-materials and their potential applications: A review". In: *Journal of Environmental Chemical Engineering* 7.1 (Feb. 2019), p. 102812. ISSN: 2213-3437. DOI: 10.1016/J.JECE.2018.102812. URL: https://0-www-sciencedirect-com.millenium.itesm.mx/science/article/pii/S2213343718307358.

[23] G. Taylor. "Electrically Driven Jets". In: *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 313.1515 (Dec. 1969), pp. 453–475. ISSN: 1364-5021. DOI: 10.1098/rspa.1969.0205. URL: http://rspa.royalsocietypublishing.org/cgi/doi/10.1098/rspa.1969.0205.

[24] A.L. Yarin. "Coaxial electrospinning and emulsion electrospinning of core-shell fibers". In: *Polymers for Advanced Technologies* 22.3 (Mar. 2011), pp. 310–317. ISSN: 10427147. DOI: 10.1002/pat.1781. URL: http://doi.wiley.com/10.1002/pat.1781.

A The Green City Index

TABLE A.1: Supplementary Table: The Green City Index. Source: (Economist Intelligence Unit 2009; Venkatesh 2014)

Categories	Indicators	Description	Normalisation technique
1. Environmental governance	1.1 Green action plan 1.2. Green management 1.3. Public participation in green policy	1.1.1 An assessment of the ambitiousness and comprehensiveness of strategies to improve and monitor environmental performance. 1.2.1 An assessment of the management of environmental issues and commitment to achieving international environmental standards. 1.3.1 An assessment of the extent to which citizens may participate in environmental decision-making.	1.1.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10. 1.2.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10. 1.3.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.

Categories	Indicators	Description	Normalisation technique
2. Carbon dioxide	2.1 Emissions 2.2 Intensity 2.3 Reduction strategy	2.1.1 Total CO2 emissions, in tonnes per head. 2.2.1 Total CO2 emissions, in grams per unit of real GDP (2000 base year). 2.3.1 An assessment of the ambitiousness of CO2 emissions reduction strategy.	2.1.1 Min-max. 2.2.2 Min-max; lower benchmark of 1,000 grams inserted to prevent outliers. 2.3.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
3. Buildings	3.1 Energy consumption of residential buildings 3.2 Energy-efficient building standards 3.3 Energy-efficient building initiatives	3.1.1 Total final energy consumption in the residential sector, per square metre of residential floor space. 3.2.1 An assessment the extensiveness of cities' energy efficiency standards for buildings. 3.3.1 An assessment of the extensiveness of efforts to promote energy efficiency of buildings.	3.1.2 Min-max. 3.2.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10. 3.3.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
4. Transport	4.1 Use of non-car transport 4.2 Size of non-car transport network 4.3 Green transport promotion 4.4 Congestion reduction policies	4.1.1 The total percentage of the working population travelling to work on public transport, by bicycle and by foot. 4.2.1 Length of cycling lanes and the public transport network, in km per square metre of city area. 4.3.1 An assessment of the extensiveness of efforts to increase the use of cleaner transport. 4.4.1 An assessment of efforts to reduce vehicle traffic within the city.	4.1.2 Converted to a scale of 0 to 10. 4.2.2 Min-max. Upper benchmarks of 4 km/km2 and5 km/km2 inserted to prevent outliers. 4.3.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10. 4.4.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.

Categories	Indicators	Description	Normalisation technique
5. Water	5.1 Water consumption 5.2 Water system leakage 5.3 Wastewater treatment 5.4 Water efficiency and treatment policies	5.1.1 Total annual water consumption, in cubic metres per head. 5.2.1 Percentage of water lost in the water distribution system. 5.3.1 Percentage of dwellings connected to the sewage system. 5.4.1 An assessment of the comprehensiveness of measures to improve the efficiency of water usage and the treatment of wastewater.	5.1.2 Min-max. 5.2.2 Scored against an upper target of 5%. 5.3.2 Scored against an upper benchmark of 100% and a lower benchmark of 80%. 5.4.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
6. Waste and land use	6.1 Municipal waste production 6.2 Waste recycling 6.3 Waste reduction policies 6.4 Green land use policies	6.1.1 Total annual municipal waste collected, in kg per head. 6.2.1 Percentage of municipal waste recycled. 6.3.1 An assessment of the extensiveness of measures to reduce the overall production of waste, and to recycle and reuse waste. 6.4.1 An assessment of the comprehensiveness of policies to contain the urban sprawl and promote the availability of green spaces.	6.1.2 Scored against an upper benchmark of 300 kg (EU target). A lower benchmark of 1,000 kg inserted to prevent outliers. 6.2.2 Scored against an upper benchmark of 50% (EU target). 6.3.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10. 6.4.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.

Categories	Indicators	Description	Normalisation technique
7. Energy	7.1 Consumption 7.2 Intensity 7.3 Renewable energy consumption 7.4 Clean and efficient energy policies	7.1.1 Total final energy consumption, in gigajoules per head. 7.2.1Total final energy consumption, in megajoules per unit of real GDP (in euros, base year 2000). 7.3.1 The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption, in terajoules. 7.4.1 An assessment of the extensiveness of policies promoting the use of clean and efficient energy.	7.1.2 Min-max. 7.2.2 Min-max; lower benchmark of 8MJ/€GDP inserted to prevent outliers. 7.3.2 Scored against an upper benchmark of 20% (EU target). 7.4.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
8. Air quality	8.1 Nitrogen dioxide 8.2 Ozone 8.3 Particulate Matter (PM) 8.4 Sulphur dioxide 8.5 Clean air policies	8.1.1 Annual daily mean of NO2 emissions. 8.2.1 Annual daily mean of O3 emissions. 8.3.1 Annual daily mean of PM10 emissions. 8.4.1 Annual daily mean of SO2 emissions. 8.5.1 An assessment of the extensiveness of policies to improve air quality.	8.1.2 Scored against a lower benchmark of 40 ug/m3 (EU target). 8.2.2 Scored against a lower benchmark of 120 ug/m3 (EU target). 8.3.2 Scored against a lower benchmark of 50 ug/m3 (EU target). 8.4.2 Scored against a lower benchmark of 40 ug/m3 (EU target). 8.5.2 Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.

B Global City Indicators Facility

TABLE B.1: Supplementary Table: Global City Indicators Facility. Source: (ISO/IEC JTC 1 Information Technology 2015; McCarney 2009)

Categories	Indicators		Supporting Indicators
City Services	Education	Student/teacher ratio Percentage	Percentage of school-aged population enrolled in schools
		Percentage of students completing primary and secondary education: survival rate	Percentage of male school-aged population enrolled in schools
		Percentage of students completing primary education	Percentage of female school-aged population enrolled in schools
		Percentage of students completing secondary education	
	Fire and Emergency Response	Number of fire fighters per 100,000 population	Response time for fire department from initial call
		Number of fire related deaths per 100,000 population	

Categories	Indicators		Supporting Indicators
City Services	Health	Number of in-patient hospital beds per 100,000 population Number of physicians per 100,000 population Average life expectancy Under age five mortality per 1,000 live births	Number of nursing and midwifery personnel per 100,000 population
	Recreation		Square metres of public indoor recreation space per capita Square metres of public outdoor recreation space per capita
	Safety	Number of police officers per 100,000 population Number of homicides per 100,000 population	Violent crime rate per 100,000 population
	Solid waste	Percentage of city population with regular solid waste collection Percentage of city’s solid waste that is recycled	Percentage of the city’s solid waste that is disposed of in an incinerator Percentage of the city’s solid waste that is burned openly Percentage of the city’s solid waste that is disposed of in an open dump Percentage of the city’s solid waste that is disposed of in a sanitary landfill Percentage of the city’s solid waste that is disposed of by other means

Categories	Indicators		Supporting Indicators
City Services	Transportation	Km of high capacity public transit system per 100,000 population	Number of two-wheel motorized vehicles per capita
		Km of light passenger transit system per 100,000 population	Commercial Air Connectivity (number of non- stop commercial air destinations)
		Number of personal automobiles per capita	Transportation fatalities per 100,000 population
			Annual number of public transit trips per capita
	Wastewater	Percentage of city population served by	Percentage of the city’s wastewater receiving primary treatment
		Percentage of the city’s wastewater that has received no treatment	Percentage of the city’s wastewater receiving secondary treatment
			Percentage of the city’s wastewater receiving tertiary treatment
	Water	Percentage of city population with potable water supply ser- vice	Total water consumption per capita (litres/ day)
		Domestic water consumption per capita (litres/day)	Percentage of water loss
		Percentage of city population with sustainable access to an improved water source	Average annual hours of water service inter- ruption per household

Categories	Indicators		Supporting Indicators
City Services	Energy	Percentage of city population	Total electrical use per capita (kWh/year) with authorized electrical service
		Total residential electrical use per capita (kWh/year)	The average number of electrical interruptions per customer per year
			Average length of electrical interruptions (in hours)
	Finance	Debt service ratio (debt service expenditure as a percent of a municipality's own-source revenue)	Tax collected as percentage of tax billed
			Own-source revenue as a percentage of total revenues
			Capital spending as a percentage of total expenditures
	Governance		Percentage of women employed in the city government workforce
	Urban Planning	Jobs/Housing ratio	Areal size of informal settlements as a percent of city area
			Green area (hectares) per 100,000 population

Categories	Indicators		Supporting Indicators
Quality of Life	Civic Engagement	Voter participation in last municipal election (as a percent of eligible voters)	Citizen's representation: number of local officials elected to office per 100,000 population
	Economy		Percentage of persons in full time employment
	Culture		Percentage of jobs in the cultural sector
	Environment	PM10 concentration	Greenhouse gas emissions measured in tonnes per capita
	Shelter	Percentage of city population living in slums	Percentage of households that exist without registered legal titles Number of homeless people per 100,000 population
	Social Equity		Percentage of city population living in poverty

Categories	Indicators		Supporting Indicators
Quality of Life	Technology and Innovation	Number of internet connections per 100,000 population	Number of new patents per 100,000 per year
			Number of higher education degrees per 100,000
			Number of telephone connections (landlines and cell phones) per 100,000 population
			Number of landline phone connections per 100,000 population
			Number of cell phone connections per 100,000 population

C Global Compact Cities Circles of Sustainability

TABLE C.1: Supplementary Table: Global Compact Cities Circles of Sustainability. Source: KPMG International (2016) (http://www.circlesofsustainability.org/circles-overview/profile-circles/)

Category	Indicators	Sub-indicators
Economics	Production & Resourcing	Prosperity and Resilience
		Manufacture and Fabrication
		Extraction and Harvesting
		Art and Craft
		Design and Innovation
		Human and Physical Resources
		Monitoring and Reflection
	Exchange & Transfer	Reciprocity and Mutuality
		Goods and Services
		Finance and Taxes
		Trade and Tourism
		Aid and Remittances
		Debt and Liability
		Monitoring and Reflection
	Accounting & Regulation	Transparency and Fairness
		Finance and Money
		Goods and Services
		Land and Property
		Labour and Employment
		Taxes and Levies
		Monitoring and Reflection
	Consumption & Use	Appropriate Use and Re-use
		Food and Drink
		Goods and Services
		Water and Electricity
		Petroleum and Metals
		Promotion and Dissemination
		Monitoring and Reflection
	Labour & Welfare	Livelihoods and Work
		Connection and Vocation
		Participation and Equity
		Capacity and Productivity
		Health and Safety
		Care and Support
		Monitoring and Reflection
	Technology & Infrastructure	Appropriateness and Robustness
		Communications and Information
		Transport and Movement
		Construction and Building
		Education and Training
		Medicine and Health Treatment
		Monitoring and Reflection

Category	Indicators	Sub-indicators
Economics	Wealth & Distribution	Accumulation and Mobilization Social Wealth and Heritage Wages and Income Housing and Subsistence Equity and Inclusion Re-distribution and Apportionment Monitoring and Reflection
Ecology	Water & Air	Vitality and Viability Water Quality and Potability Air Quality and Respiration Climate and Temperature Greenhouse Gases and Carbon Adaptation and Mitigation Processes Monitoring and Reflection
	Flora & Fauna	Complexity and Resilience Biodiversity and Ecosystem Diversity Plants and Insects Trees and Shrubs Wild Animals and Birds Domestic Animals and Species Relations Monitoring and Reflection
	Habitat & Settlements	Topography and Liveability Original Habitat and Native Vegetation Parklands and Reserves Land-use and Building Abode and Housing Maintenance and Retrofitting Monitoring and Reflection
	Built-Form & Transport	Orientation and Spread Proximity and Access Mass Transit and Public Transport Motorized Transport and Roads Non-motorized Transport and Walking Paths Seaports and Airports Monitoring and Reflection
	Embodiment & Food	Physical Health and Vitality Reproduction and Mortality Exercise and Fitness Hygiene and Diet Nutrition and Nourishment Agriculture and Husbandry Monitoring and Evaluation

Category	Indicators	Sub-indicators
Ecology	Emission & Waste	Pollution and Contamination Hard-waste and Rubbish Sewerage and Sanitation Drainage and Effluence Processing and Composting Recycling and Re-use Monitoring and Evaluation
Politics	Organization & Governance	Legitimacy and Respect Leadership and Agency Planning and Vision Administration and Bureaucracy Authority and Sovereignty Transparency and Clarity Monitoring and Reflection
	Law & Justice	Rights and Rules Order and Civility Obligations and Responsibilities Impartiality and Equality Fairness and Prudence Judgement and Penalty Monitoring and Reflection
	Communication & Critique	Interchange and Expression News and Information Accessibility and Openness Opinion and Analysis Dissent and Protest Privacy and Respect Monitoring and Reflection
	Representation & Negotiation	Agency and Advocacy Participation and Inclusion Democracy and Liberty Access and Consultation Civility and Comity Contestation and Standing Monitoring and Reflection
	Security & Accord	Human Security and Defence Safety and Support Personal and Domestic Security Protection and Shelter Refuge and Sanctuary Insurance and Assurance Monitoring and Reflection

Category	Indicators	Sub-indicators
Politics	Dialogue & Reconciliation	Process and Recognition
		Truth and Verity
		Mediation and Intercession
		Trust and Faith
		Remembrance and Redemption
		Reception and Hospitality
		Monitoring and Reflection
	Ethics & Accountability	Principles and Protocols
		Obligation and Responsibility
		Integrity and Virtue
		Observance and Visibility
		Prescription and Contention
		Acquittal and Consequence
		Monitoring and Reflection
Culture	Identity & Engagement	Diversity and Difference
		Belonging and Community
		Ethnicity and Language
		Religion and Faith
		Friendship and Affinity
		Home and Place
		Monitoring and Reflection
	Creativity & Recreation	Aesthetics and Design
		Performance and Representation
		Innovation and Adaptation
		Celebrations and Festivals
		Sport and Play
		Leisure and Relaxation
		Monitoring and Reflection
	Memory & Projection	Tradition and Authenticity
		Heritage and Inheritance
		History and Records
		Indigeneity and Custom
		Imagination and Hope
		Inspiration and Vision
		Monitoring and Reflection

Category	Indicators	Sub-indicators
Culture	Belief & Ideas	Knowledge and Interpretation
		Ideologies and Imaginaries
		Reason and Rationalization
		Religiosity and Spirituality
		Rituals and Symbols
		Emotions and Passions
		Monitoring and Reflection
	Gender & Generations	Equality and Respect
		Sexuality and Desire
		Family and Kinship
		Birth and Babyhood
		Childhood and Youth
		Mortality and Care
		Monitoring and Reflection
	Enquiry & Learning	Curiosity and Discovery
		Deliberation and Debate
		Research and Application
		Teaching and Training
		Writing and Codification
		Meditation and Reflexivity
		Monitoring and Reflection
	Health & Wellbeing	Integrity and Autonomy
		Bodies and Corporeal Knowledge
		Mental Health and Pleasure
		Care and Comfort
		Inclusion and Participation
		Cuisine and Emotional Nourishment
		Monitoring and Reflection