New York State Energy Research and Development Authority

Sustainable Urban Agriculture:
Confirming Viable Scenarios for Production

Final Report

March 2013

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Sustainable Urban Agriculture: Confirming Viable Scenarios for Production

Final Report

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NOTICE

ABSTRACT

This feasibility study broadly evaluates the viability of urban and peri-urban food production techniques compared with rural food production. Specific case study scenarios are presented to examine whether urban food production can be practiced in an economical and resource efficient manner. The study focuses specifically on New York City to determine potential production sites and establish which methods of alternative agriculture production would be most appropriate. Further research is suggested to establish costs and benefits from the perspective of energy use, other environmental and health metrics, and economics.

KEY WORDS

Urban agriculture

Horticulture

Controlled environment agriculture

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Given that New York City (NYC) is the most densely developed metropolis in the U.S., site availability and land values are primary factors limiting the expansion of urban agriculture.

Potentially available space for agriculture in NYC includes the following land use designations:

- Private vacant land: 3,321 acres
- Public vacant land: 1,663 acres
- Existing community gardens: 86 acres
- New York City Housing Authority (NYCHA) green space: 978 acres

Rooftops

- Privately owned buildings: 2,703 acres
- Public buildings: 376 acres

In 2006, there were a total of 394,253 acres of agricultural land in the NYC Metropolitan Statistical Area (MSA), or 9.2 percent of the total land area. Small- to medium-scale farming is the dominant form of agricultural activity in this peri-urban area. Average market value of products sold per farmland acre in the region was $1,610 in 2007, as compared to an average of $616 per acre in New York State as a whole. There are also challenges with loss of active farmland – 368,884 acres of the total agricultural land in the NYC MSA was actively farmed in 2007 – a decrease of almost 14 percent from 1997. Some counties, such as Rockland and Bergen, lost close to 60 percent of their active farmland during that ten-year period.

Between 162,000 and 232,000 acres are needed to supply NYC's stores with fruits and vegetables, not including the approximately 886 million pounds of tropical or warm-weather fruit consumed annually by New Yorkers which cannot be grown locally. Converting all of the potentially suitable vacant land in NYC (estimated at 4,984 acres) to agriculture with an average growing area of 70 percent of lot area could supply the produce needs of between 103,000 and 160,000 people. Between 46 and 71 percent of the 368,884 acres of active farmland in the counties comprising the NYC MSA would be sufficient to supply the fruit and vegetable needs of NYC residents (excluding warm-weather fruit). If the total population of 18,897,109 of the NYC MSA is taken into account, the agricultural land of the region could support between 58 and 89 percent of the of the region's fruit and vegetable needs, were that land dedicated entirely to production for local markets.

There are a number of neighborhoods where a confluence of factors makes urban agriculture a particularly attractive and effective means of addressing multiple challenges. These include low access to healthy food retail, high prevalence of obesity and diabetes, low median income, and comparatively high availability of vacant and other available land. These factors are all correlated, and it is in these areas where urban agriculture could have the greatest impact on food security. Neighborhoods which fit the pattern of inadequate healthy food access, high incidence of diet-related disease, greater percentage of vacant land, etc., include East New York, Brownsville, Crown Heights, Bedford-Stuyvesant, and Bushwick in Brooklyn, the Lower East Side and East and Central Harlem in Manhattan, and Morrisania, Claremont Village, East Tremont, and Belmont in the Bronx, among others.

Urban agriculture can often function as a means of generating economic value from otherwise vacant or underutilized space. As such, it can be argued that urban agriculture is generally an additive, as opposed to substitutive, form of economic development, creating value from sites, which for whatever reason are not suitable or attractive for other uses. These sites include rooftops, which comprise a large percentage of the city's land cover, and represent an opportunity for property owners to extract rent from an otherwise unused space.

Leaf Area Index (LAI), soil depth, irrigation, and existing roof insulation are the four most influential factors in determining the energy impact of a green roof on the host building. Rooftop farms differ substantially from standard green roofs as far as these factors as concerned. Generally speaking, a green roof with a high LAI is expected to contribute greater building energy benefits. Another important consideration is that vegetables' LAI will vary with the seasons, while sedum remains relatively constant and is selected specifically for winter hardiness. The greater cover canopy of vegetables in summer could lead to greater energy benefits for the host building during the summer, while not impeding solar gains into the building from the roof when the crops lie dormant in the winter. Although thicker, less dense growing media characteristic of standard green roofs may offer better insulation to the building below, the actual impact of soil moisture content is still uncertain.

Controlled Environment Agriculture (CEA) energy inputs are primarily in the form of electricity and natural gas. The competitiveness of such operations compared to field production, especially those distributing locally or regionally, is heavily influenced by the relative price of petroleum versus natural gas and sources of electricity generation. Geographic differences in energy prices are likely to have an effect as well. New York City, for example, has some of the highest electricity prices in the nation, with the average commercial retail price considerably higher than that of utilities in the peri-urban area.

Rigorous research on quantifying the energy savings from building-integrated greenhouses is still lacking. Comprehensive studies should take into account the convective dynamics and thermal storage of the integrated system as well as nuanced temperature and insolation profiles. Pending more in-depth research, the consensus seems to be that the energy impacts of a rooftop greenhouse are similar to that of a green roof, but are especially beneficial to poorly insulated buildings. Conversely, the cost of constructing a rooftop greenhouse is approximately three times that of installing a green roof, though if properly designed and managed, annual yields may be an order of magnitude higher than for an outdoor rooftop farm.

Evaluation of food system energy inputs should consider the embedded energy per unit food delivered. This metric would account for the effect of systems scale on food loss along the entire value chain, which is an increasingly important consideration, given that per capita generation of solid food waste increased 14.5 percent between 1990 and 2000 and an additional 10.1 percent between 2000 and 2007. Anticipating reduced losses as well as food-miles traveled, applying such a metric could reveal substantial benefits in favor of localized farming with leaner distribution networks. Instead, we propose an assessment of energy input per mass delivered to consumers.

The smaller volumes and greater diversity of product that is characteristic of small-scale farming approaches, combined with close proximity to a large consumer base, enables growers to market products to consumers directly, thereby reducing the number of intermediaries. Direct marketing arrangements, which capitalize on small-scale polycultural production approaches such as CSA, may represent the most efficient way to take advantage of urban growing conditions.

Agricultural operations on smaller plot sizes make capital-intensive, mechanized equipment hard to justify from an economic standpoint; instead, operations must rely to a higher degree on manual labor. In such regimes, the growing practices can be considered from the perspective of monoculture versus polyculture growing practices. With current technology, mechanized equipment is ill suited to accommodate the production of intercropped cultures, whereas manual labor should have little difficulty handling two or more crops grown side by side. Planting different crops side-by-side has the potential to make the land 'biologically over-yielding' (i.e., the total crop yield in a polyculture exceeds the yield from the same amount of land where each crop is grown as a monoculture in the same proportions). Furthermore, the various combinations of crops that render such an outcome feasible also have the possibility of being economically over-yielding; meaning that the land output value also exceeds the monoculture counterpart.

Specialty crop production requires especially high direct energy inputs. On-farm energy use for specialty crops accounts for a much higher percentage of total value chain energy use than for other types of foods. This reflects the fact that, despite involving less mechanized planting and harvesting techniques, fruits and vegetables require more involved and energy intensive handling, storage, and refrigeration post-harvest, and some of these activities take place on farms. Compared to conventional, larger-scale agriculture, soil-based urban farms are likely to use less direct energy during the production phase, as manual energy largely supplants mechanical energy.

Hedging price risk in financial markets is usually not an option for small-scale producers, especially those who grow specialty crops, because individual volumes are too small or to a lack of sufficient trading of the produce grown. Furthermore, obtaining crop insurance for specialty crops grown on smaller plot sizes is much more difficult due, in part, to the sometimes very detailed quality assurances.

Although small-scale farms face a greater difficulty compared to larger farms to protect against risk using conventional means, the opportunity of resolving price risk and to some extent also production risk by entering into marketing contracts directly with the end-consumer is more tractable on a local scale. Smaller production volumes more closely match the demand from single local customers, such as restaurants or perhaps individual markets, making the logistics manageable without a third party.

Chapter One. Agricultural Techniques and Approaches with the Greatest Potential for New York City

Developing agricultural capacity within or close to urban areas such as New York City (NYC) has the potential to reduce transportation costs and environmental impacts, provide economic development opportunities, and increase access to healthful food. Despite these potential advantages, there are challenges to establishing the viability of urban production as compared to more conventional agricultural practices, including scalability, site availability, energy efficiency, and labor costs. While small-scale food production practices such as community gardening are already an established component of the NYC food system, scalable projects that would significantly impact the food system must be established and rigorously evaluated to effectively advocate for their implementation.

Urban agriculture is gaining traction in many cities across the U.S. The movement is generating the greatest amount of excitement and interest in places such as Detroit, Cincinnati, and other Rust Belt cities suffering from decades of economic decline and population loss, where reclaiming the vast areas of vacant or abandoned land through farming is part of larger efforts aimed at revitalization. The situation in NYC is quite different, in that it is the highest-density U.S. metropolis, and has some of the nation's highest land values, making the prospect of farming in the five boroughs a more challenging proposition. On the other hand, NYC has particular advantages: the economic and cultural robustness that serve to maintain high property costs are also associated with a high level of awareness and support (and potential access to investment capital) for projects that promote healthy food systems and sustainability. Urban farms are uniquely dependent on their surrounding communities to provide a strong customer base, and NYC's density and diverse and vibrant food culture make for an attractive context for aspiring urban farmers. And despite what some might assume to be an inhospitable climate for agriculture, the five boroughs have a rich farming history, with Queens and Kings Counties being among the most productive agricultural counties in the nation in the late 19th century, all before the advent of advanced season-extension techniques (Linder and Zacharias, 1999). Given the relative novelty of commercial-scale food production in densely populated areas in the U.S., there is a dearth of information regarding the long-term viability of the practice and potential implications on water and energy use. This study is an attempt to address these issues by developing methodologies from which to evaluate urban agriculture from the perspective of scale and energy inputs.

1.1. Viable production approaches

There is a wide variety of approaches to urban agriculture to consider in the context of NYC's environmental, social, and economic conditions. These range from small scale, dispersed, homegrown or community based efforts, such as urban homesteading or community gardening to high-tech, capital-intensive, commercial projects such as rooftop greenhouses or "vertical farming." Given this broad range, we have chosen to focus on approaches, which fulfill two distinct criteria: demonstrated technical feasibility, and potential for commercial-scale viability. Using these criteria, we have identified three broad categories of food production in urban areas, based on spatial typology: ground-based agriculture, rooftop agriculture, and indoor (controlled environment) agriculture. For a detailed discussion of these approaches, see Section 1.4.

1.2. ArcGIS and other data collection

Spatial data collected from a variety of NYC agencies determined the types and distribution of potential sites for urban agriculture. Three spatial data sets obtained data on vacant land and community gardens. The first is a polygon shapefile of the tax parcels in NYC with attribute values from the Department of City Planning (DCP) PLUTO database, dated June 2009. The second set is a polygon shapefile of the wetlands in New York State made available through the U.S. Fish and Wildlife Service's National Wetlands Inventory website, dated October 2010. The third is a community garden shapefile obtained from researchers at the Farming Concrete project in January 2011. Vacant parcels were determined through the PLUTO data attributes for the tax parcel features. Specifically, those features with '11' as a value for the 'LandUse' field were determined to be vacant. A review of the values for the 'OwnerName' field determined public or private ownership. The public and private vacant land groups were then intersected with the wetlands shapefile using the 'Erase' function of the 'Analysis' tools in ArcMap to determine the total areas of each which reside within and outside of wetlands. Manual verification of the largest vacant parcels as well as an analysis of over a hundred lots in all five boroughs listed as vacant were then conducted using Google Earth satellite imagery and Bing Maps aerial imagery. Based on this analysis it was determined that many of the parcels characterized as "vacant" are in fact developed or appear to be in active use (e.g., as a sports or recreation area). Such parcels comprise approximately 12 percent of the total vacant area. Further assessment of vacant land based on satellite imagery reveals that over 1,000 acres, primarily in Staten Island, are heavily forested, with several hundred additional "vacant" acres being located within on or around the Fresh Kills landfill (future site of the Freshkills Park). These areas were subtracted from the total vacant land and data was then tabulated by borough. The community garden shapefile was also modified and some areas subtracted based on verification using satellite imagery. Public vacant land data was obtained using the same methodology as above, only isolating those properties where 'OwnerName' is a NYC agency. Parcels were then divided into categories by area.

Information on other potential sites for urban agriculture was created using a variety of sources. The unused open spaces were determined using a polygon shapefile of all the open spaces in NYC as of November 2007, which is available through the City's Department of Information Technology and Telecommunications website. Open spaces were determined to be unused if they had one of the following values for the 'LANDUSE' field: 'EMPTY LOT,' 'TRIANGLE,' or 'Undeveloped'. The majority of these open spaces fall within public rights-of-way, meaning they are not on a tax lot. However, a minority of these spaces exists on tax lots; these are exclusively owned by the City and under the jurisdiction of the Department of Parks and Recreation. NYC Housing Authority (NYCHA) green space was mapped using data from the DCP PLUTO database, dated June 2009. Properties with values for the 'OwnerName' corresponding to some variation of NYCHA ("New York City Housing," "Housing Authority," etc.) were selected. Vacant lots and administrative buildings were then deleted from the selection, as were building footprints. Based on detailed assessments of plans and aerial imagery of ten housing clusters throughout the city, we estimated that approximately 50 percent of developed NYCHA property (not including building footprints) consists of green space. This green space sums to a total of approximately 978 acres (this figure does not include parking, walkways, or recreation areas on NYCHA property; nor does it include vacant NYCHA property which is part of the vacant land inventory). The housing developments analyzed are: Jackson/Melrose (the Bronx), Edenwald/Baychester (the Bronx), Jacob Riis (Manhattan), Polo Grounds Towers (Manhattan), Kings Towers (Brooklyn), Sheepshead Bay/Nostrand (Brooklyn), Brownsville/Tilden/Hughes/Van Dyke I (Brooklyn), Red Hook (Brooklyn), Queensbridge (Queens), and Mariner's Towers (Staten Island). Greenstreets and surface parking are both polygon shapefiles from the PLUTO database.

The potential rooftop farming in NYC was evaluated using two spatial data sets. The first is a polygon shapefile of current NYC zoning, effective November 2010 and made available through the DCP website. The second set is a polygon shapefile of building footprints in NYC prepared by the NYC Department of Information Technology and Telecommunications, dated March 2009. The data set includes additional attributes from an undisclosed entity but most likely the DCP. Buildings were originally selected to meet four criteria: 1) a footprint greater than or equal to 10,000ft^2, 2) a 'YearBuilt' value between 1900 and 1970, 3) inclusion in manufacturing, commercial, or commercial overlay, and 4) 10 stories or lower. These results were divided into two categories by the assumed area of the roof (attribute: 'Shape_Area'); 1) 10,000ft^2 – 25,000ft^2 and > 25,000ft^2. Additional criteria were applied to further filter these results using the attributes for the building footprint features; these are 'BuiltFAR', 'MaxAllwFAR', and 'BldgClass'. Excluded buildings were those characterized as heavy manufacturing, garage and gas station, utilities, and categories deemed otherwise unsuitable for farming (including bridges, tunnels, highways, electric utilities, gas, ceiling railroad, telephone utilities, communications facilities, and revocable consents).

1.3. Types and distribution of sites in NYC that could have potential for production

Given that NYC is the most densely developed metropolis in the U.S., site availability and land values are primary factors limiting the expansion of urban agriculture. Despite the slump in new real estate development in NYC over the past few years, property values remain among the highest in the nation (among cities over one million), and the city continues to grow. The Department of City Planning (DCP) rezoning plans remain focused on upzoning in response to increasing demands for housing and commercial development, and the remaining underdeveloped areas will continue to dwindle in the face of increasing densification. In the near term, it is unlikely that urban farming will be able to compete with other land uses such residential development on the open market by purchasing land to farm. For any unused or underutilized space there are often many interested parties with competing interests, including private developers in search of profit, municipal agencies or community groups wishing to increase supportive housing or other key public services, or neighborhood residents who wish to have more open space or recreational facilities. All of the above programs are vital to maintaining a livable city, and urban agriculture should not take priority over these other potential uses. However, despite the land access challenges discussed above, there remains a substantial amount of potentially available land in the five boroughs. What follows is a breakdown of the different types of urban spaces for possible agricultural use, including vacant lots, open space, NYCHA property, parking lots, greenstreets, backyards, and rooftops. This is by no means a comprehensive or definitive survey of all available land: transportation and utility easements, for example, are not included, nor are underdeveloped or underutilized areas that do not fall under one of these categories. The analysis represents an attempt to come up with the most accurate figures possible for available land within the limitations of the existing data. This information, while not complete, can begin to inform decisions that could encourage targeted approaches to the development of urban agriculture in NYC.

1.3.1 Vacant Land

Broadly speaking, vacant lots are lots on which there are no habitable structures or which have no other current designated use. According to the DCP MaPLUTO 2010 database, there are 8,562 acres of vacant land in NYC, of which 3,654 acres are public land under the jurisdiction of a municipal, state, or federal agency. The balance of the vacant land is private property. While vacant land is NYC's greatest opportunity for conversion to urban agriculture, not all of the land classified as vacant is in fact available or suitable for such use. The DCP vacant land figures include many community gardens, lots with an existing designated use, and lots that include both vacant land and existing structures. On Staten Island in particular, much of the land classified as vacant is either federally designated wetland or heavily forested land owned by the Department of Environmental Protection. Neither of these environments is likely to be suitable for farming, due to the difficulty of establishing a farm on such sites as well as the problems inherent in converting valuable ecological resources such as wetland or forest to food production. After subtracting wetlands, forested areas, community gardens that are designed as vacant land, and other lots which in reality are occupied by buildings or other active uses, there remain 4,984 acres (1,663 acres of public land and 3,321 acres of private land), much of which could be used for urban agriculture. The distribution of these sites is shown in Figure 1.1. There are many small-scale, vacant sites scattered throughout the neighborhoods of Brownsville, East New York, and Crown Heights in Brooklyn, East Harlem in Manhattan, Ozone Park and Jamaica in Queens, the South Bronx, and Northern Staten Island. Large vacant sites are located primarily in Staten Island, but also in the Queens neighborhoods of College Point and the Rockaways, and East New York. Because of decades of development pressure, many vacant lots in NYC are sites, which are either too small or otherwise not suited for residential or commercial development. Urban agriculture could be an ideal means with which to rehabilitate such areas and transform them from a potential blight into an asset for the community.

Public vacant land represents the greatest opportunity for urban agriculture because specific uses can be directly determined or incentivized through municipal land-use policy changes. The sites shown in Figure 1.2 consist primarily of otherwise unutilized and inaccessible land owned by municipal agencies such as the Department of Housing, Preservation and Development, Department of Parks and Recreation, the Department of Transportation, the Department of Education, etc., but also land under the jurisdiction of state and federal agencies. Excepting Staten Island, many of these sites are concentrated in low-income neighborhoods, which could benefit the most from the establishment of urban agriculture.

Private, vacant land is also a possibility for agricultural sites. Policies to consider to encourage the use of such land for food production include tax incentives or a combination of a vacant lot tax penalty and farming exemption. This could be cost neutral or even beneficial to the City, especially given that properties values surrounding cultivated green areas tend to be higher than those surrounding unkempt vacant lots (Been and Voicu, 2007). One of the complicating issues is that establishing a viable farm involves a great deal of sweat equity, often invested over the course of years, in building up healthy soils (especially in urban areas) and establishing a productive landscape. Urban farmers may be loath to establish a farm on a privately owned lot where there is no guarantee of long-term tenure. Precedents such as the new community garden rules of 2010 offer some long-term protection from development, are important in this regard, even though many community garden advocates view the new rules as inadequate. Paradoxically, such protections may act as disincentives for private property owners, who rightly or wrongly may assume that allowing urban agriculture on their property may jeopardize future plans for the property or property values, whether due to actual legal protection for existing farms or because of community opposition to the removal of an existing farm. Some urban farmers are dealing with potential land insecurity by developing modular, moveable-farming systems, such as transportable beds. There is much to learn from other cities on how to incentivize farming on vacant private land. San Francisco, for example, has a policy whereby developers who obtain building permits, but do not have adequate financing in place, can receive extensions to the permits if they permit urban agriculture to take place on the site in the meantime (as opposed to having to re-file for permits). For many private vacant lots, especially those that have been vacant for several years or longer, urban agriculture could be an attractive, low to no cost (for the owner) means of rehabilitating or using the space.

Figure 1.1. Vacant Land and Community Gardens in NYC.

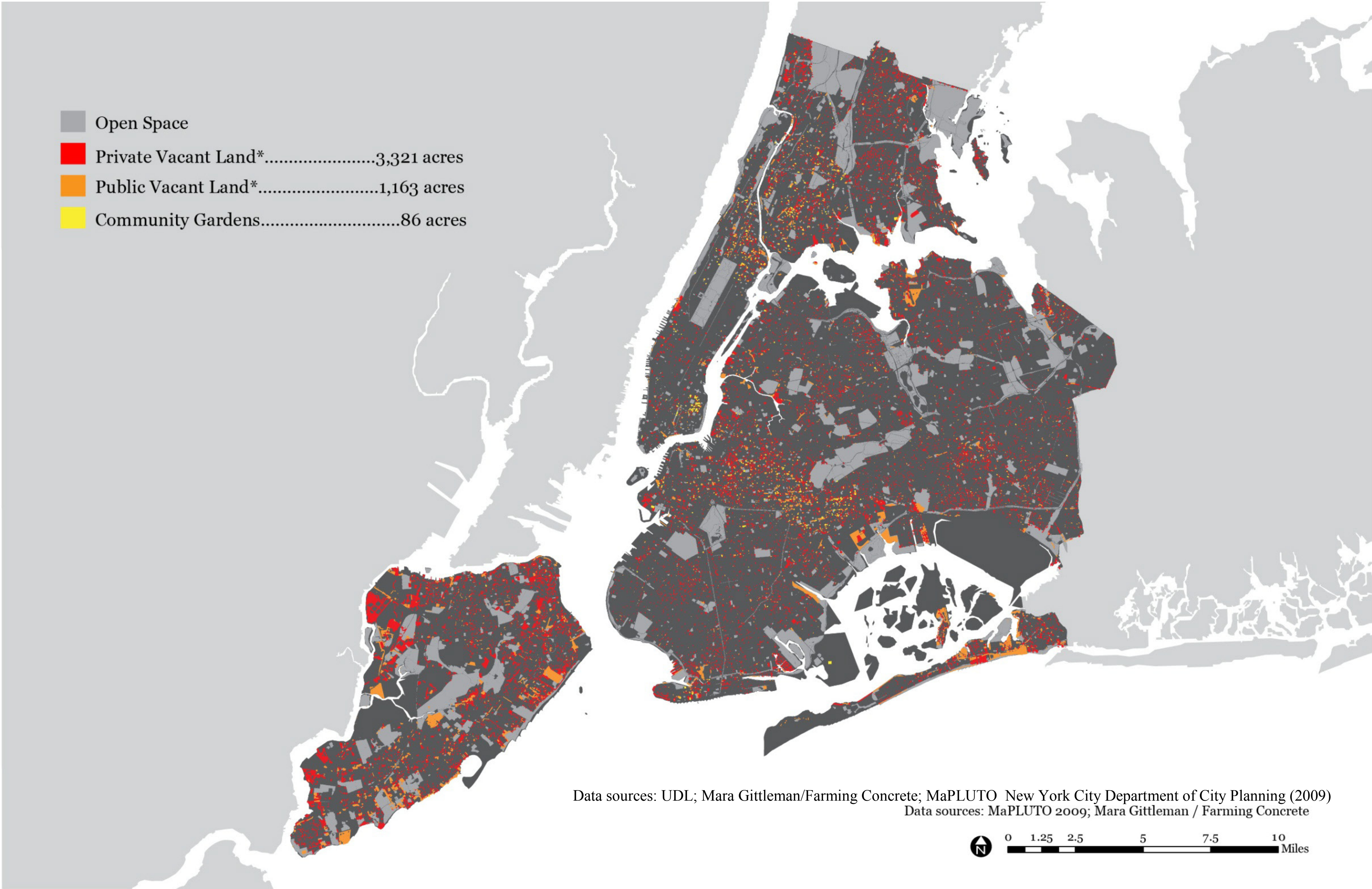
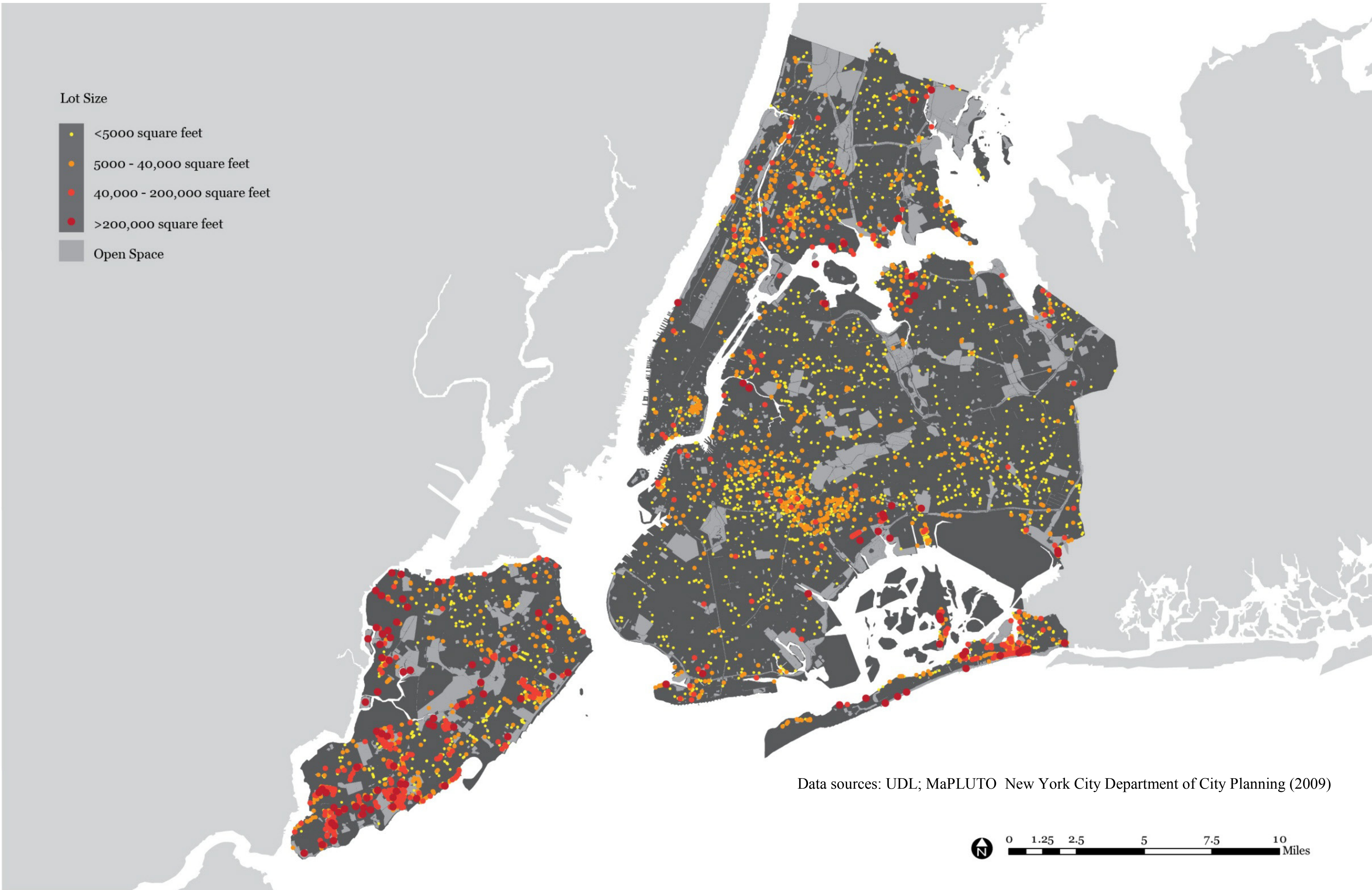


Figure 1.2. Public Vacant Land in NYC.

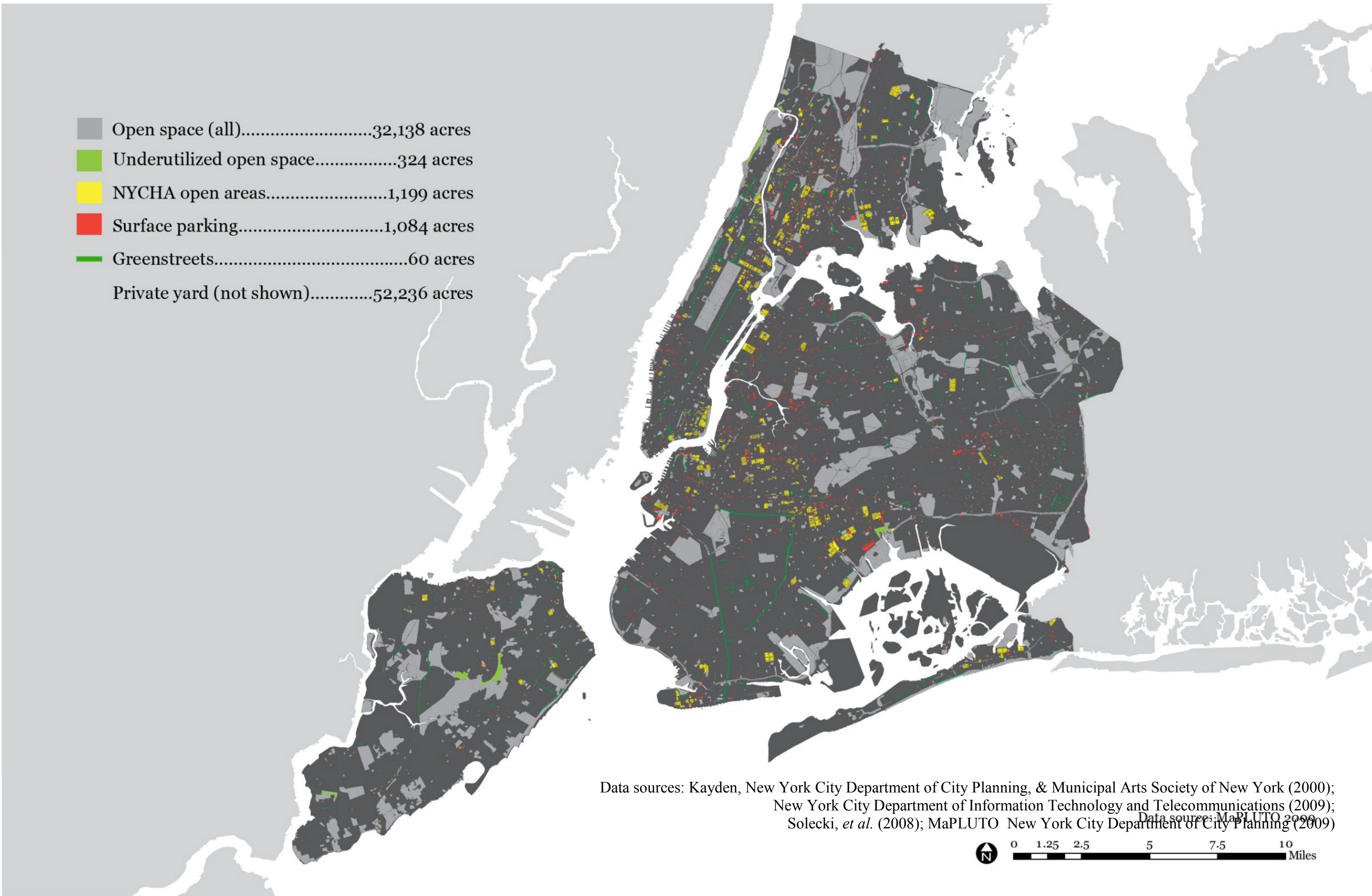


1.3.2 Open Space

Open Space, as defined by the DCP, includes public parks, playgrounds and nature preserves, cemeteries, amusement areas, beaches, stadiums and golf courses. There are 52,938 acres of open space, which represents over one-quarter of the city's total area, making NYC one of the "greenest" cities in nation. Most of this land is well used by the public and provides critical wildlife habitat and other ecosystem services, and in such areas, it would be inappropriate to farm. There could be an important role for urban agriculture within parkland, however, as it could complement the public uses, assist with environmental restoration, and contribute to other economic and cultural activity. The redevelopment plan for Governor's Island is an interesting example of how to creatively assimilate these various priorities and programs, including urban agriculture. Another interesting opportunity is the 1,358-acre Floyd Bennett Field, which is part of the Gateway National Recreation Area, and which is the target of a major soil cleanup project as well as a strategic planning process. Already a consortium of interested parties has developed a strong plan for the creation of a farm and urban agriculture education and training center on the site.

With so much land designated as open space, there are inevitably underused areas, and the appropriateness of locating farming within urban parkland would have to be evaluated on a case-by-case basis. Other than parkland, potential underutilized open space areas include areas within parks, triangle spaces within intersections, and other underdeveloped areas. Collectively these categories in MaPLUTO account for 324 acres, after the subtraction of wetlands. This figure certainly represents a very low estimate of underutilized open space, as it includes only lots that are entirely classified as such – underused or neglected areas within larger parks or open space lots could add up to hundreds of additional acres. In northern Manhattan, for example, portions of Jackie Robinson and Highbridge Parks have been inaccessible and unmaintained for years, and it quite possible that within these parks there are areas which could be used for food production. Of course, the prospect of commercial food production on public parks is unlikely and probably inadvisable, given their status as a public resource, but community-based or non-profit farming could be one way of revitalizing some of NYC's neglected park areas. For a map of open space and other land designations mentioned in this section, see Figure 1.3.

Figure 1.3. Other Potential Sites for Urban Agriculture in NYC.



1.3.4 New York City Housing Authority property

There is significant potential for cultivation of land on NYCHA property, which is concentrated in the low-income neighborhoods of the South Bronx, East Harlem, Bedford-Stuyvesant, Crown Heights, Brownsville, and East New York. The agency's Gardening and Greening Program has helped to establish 645 gardens in housing developments, of which 254 grow vegetables. NYCHA is looking to expand farming and gardening in green spaces in housing developments, with the aim of establishing 129 additional community gardens and at least one urban farm. Based on detailed assessments of ten NYCHA housing clusters in various parts of the city, we estimate that approximately 50 percent of developed NYCHA property, not including building footprints, consists of green space. This green space totals about 978 acres (this figure does not include parking, walkways, or recreation areas on NYCHA property; nor does it include vacant NYCHA property, which is part of the vacant land inventory). Some of that space is well maintained and appreciated by residents for its recreational value, and trees and buildings shade much of the green area. Some open space areas are under consideration for the construction of new facilities. There is open space in many of the developments, which is difficult to access, poorly maintained, or underutilized. These areas would be most appropriate for the creation of new gardens and farms should residents support such measures.

1.3.5 Surface parking

While it may seem hard to believe in a city where parking seems to be perpetually in short supply, there are over 1,084 acres of surface parking lots in the five boroughs. (This figure includes only surface lots that are entirely parking. Street parking and parking areas that are on commercial or residential properties, such as for office buildings or malls, are not included in this figure; nor are indoor parking facilities or garages, so the amount of actual parking area is much greater.) Some of these lots–particularly in the outer boroughs–are underused, essentially vacant, or used for temporary storage of equipment or material. Surface parking is an important asset in any city, but because such spaces consist of large paved surfaces, they contribute disproportionately to stormwater runoff (and hence combined sewer overflow [CSO] events) and urban heat island effect. Parking lots are a key target for stormwater mitigation, and the NYC Green Infrastructure Plan calls for creating planted permeable swales on more of these sites (NYC Department of Environmental Protection [DEP], 2010). Partial or total conversion of parking areas to urban agriculture and other forms of green infrastructure could be encouraged by the imposition of fees for stormwater runoff from properties with large uninterrupted swaths of impermeable area, combined with credits or other incentives for onsite mitigation. Calculating how much existing surface parking is underutilized is beyond the scope of this report, but there are likely to be tens if not hundreds of acres that could be productively converted to farming and gardening without significantly impacting parking availability.

1.3.6 Greenstreets

Greenstreets such as Park Avenue, Ocean Parkway, and Eastern Parkway are landscaped traffic islands and medians, some of which could be suitable for fruit tree cultivation, although fruit trees in this climate are especially susceptible to pests, and pesticide application in these sites would be problematic. Our analysis using MaPLUTO identified 170 acres of greenstreets in the five boroughs. The major issue with converting greenstreets for food production is access and pollution. On busy thoroughfares, accessing the medians could pose a safety hazard. Unless any agricultural activity taking place in such spaces is designed to be completely open to the public for participation and harvesting (and potential vandalism), access would have to be restricted, which is contrary to the spirit of the program. Pollution from adjacent vehicular traffic could also pose a risk, primarily for anyone working in these medians, and because of potential contamination of the produce. Despite such these challenges, cities such as Seattle have had some success with food cultivation in (somewhat wider and not heavily trafficked) street medians. PlaNYC has committed funding for 80 new greenstreets, each with the goal of reaching 3,000 total by 2017 (The City of New York, 2011). Another related initiative is the Department of Transportation (DOT) Plaza Program, which aims to create public-use open space in the right of way. There may be potential to incorporate urban agriculture into such plazas, although given that the priority of the program is to create easily accessible open space, it could be a challenge to establish any sort of large-scale food production.

1.3.7 Yard Space

There is more private yard space in NYC than many people imagine. An unpublished report from 2008 used a GIS analysis to calculate that there are 52,236 acres of residential yard space in the five boroughs (Solecki *et al.,* 2008). This is an area almost equal to the area of public open space (this figure includes the area on residential lots that is not covered by the building footprint; it does not indicate how much of this area is currently green space or planted). This represents a huge opportunity for food production in the city, and many residents are already using such space for private gardens. While it is unlikely that backyard gardening will reach commercial scale, innovative programs in a number of cities have focused on connecting property owners with farmers, who cultivate this space in exchange for a portion of the yield which is returned to the landowner. The closest analogue to such an approach in NYC is BK Farmyards, which operates a CSA (community supported agriculture) on this model. Additionally, historical precedent has demonstrated that small-scale private food cultivation can have an impact on food security. During the First and Second World Wars, the Victory Garden program was designed to relieve food shortages and boost morale during wartime. This program was so successful in motivating citizens to use their backyards (and in some cases, rooftops) for food cultivation that during the height of the program in the 1940's as much as 40 percent of the nation's produce was grown in such gardens (Bently, 1998). While no such equivalent program exists today, sales of seed and garden equipment have been rapidly increasing in all parts of the nation over the past few years (Horovitz, 2009), pointing to a resurgence in gardening.

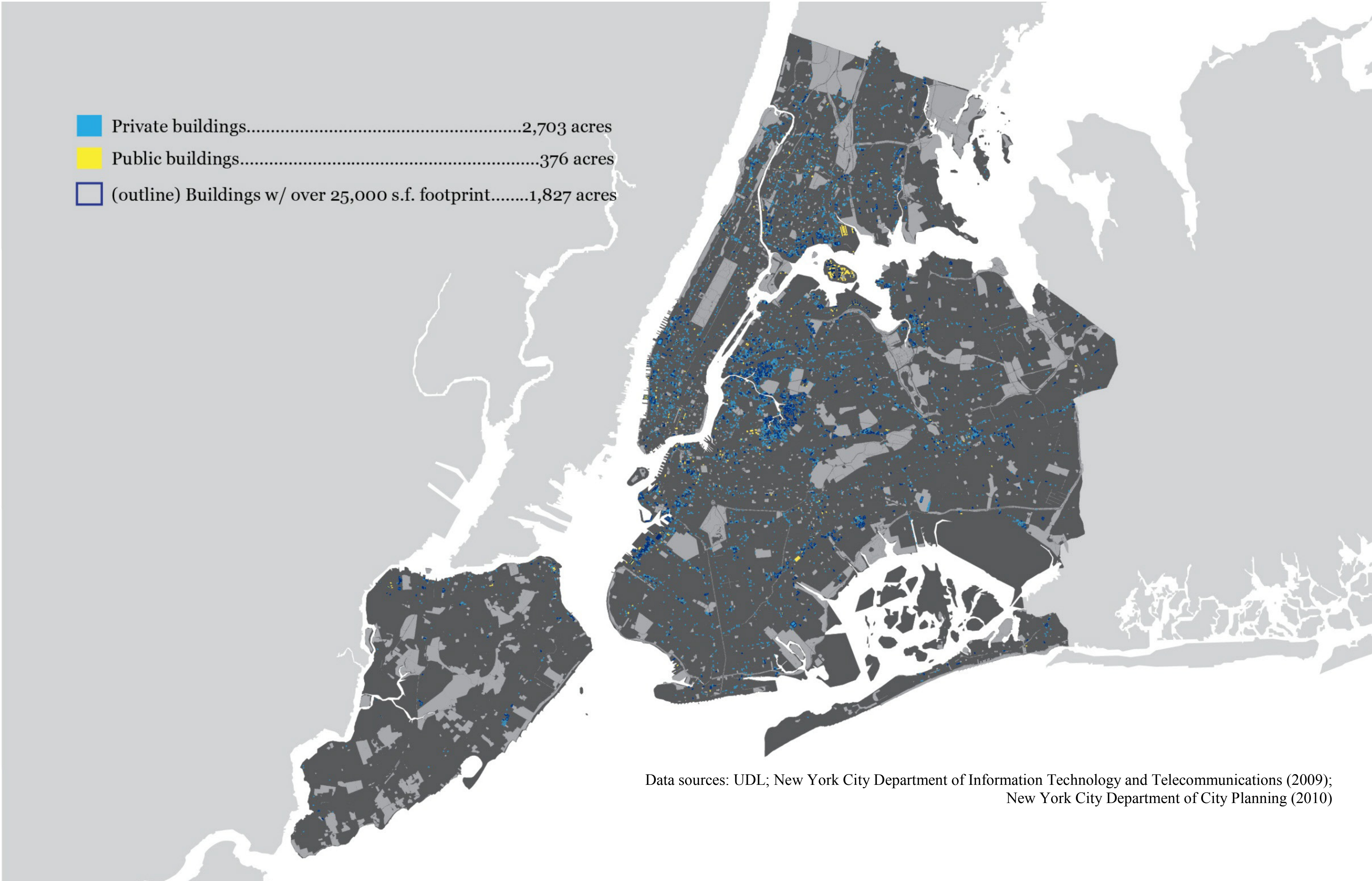
1.3.8 Rooftops

Due in part to the density and high land values in NYC, rooftop agriculture has become more established in the city. There are approximately one million buildings in NYC, with 38,256 total acres of rooftop area. The most prevalent building type is one- or two-family houses (NYC DCP, 2010), many of which have sloped roofs, while others may be too tall, too small, or otherwise unsuited for rooftop farming. There are many multi-family residential buildings in the city as well, a majority of which have flat roofs and could support small-scale food production. For the purposes of this study, we are focusing on larger commercial and industrial properties that could be suitable for a larger-scale rooftop farm. These are shown in Figure 1.4: *Potential Rooftop Farming in NYC*. These structures were selected using the following criteria:

1) Located in manufacturing and commercial districts, as industrial buildings are often more structurally robust, and such zones allow for commercial activity;
2) Built between 1900 and 1970, when building codes mandated greater roof live load requirements; generally, buildings built before 1970 were built to withstand up to 50lbs/ ft2 rooftop live load, and live load requirements have been decreasing since then.
3) Have a footprint of over 10,000 ft2 – although plant cultivation is possible on roofs of any size, experienced rooftop farmers have noted that economic viability of farming on smaller roofs is uncertain (unless a cluster of adjacent roofs were used for the purpose);
4) 10 stories tall or lower; although there is no hard and fast rule regarding a height above which climatic conditions become inhospitable for food crops (and people), conversations with rooftop farmers led us to impose this value as a reasonable restriction. Additionally, growing above ground level involves challenges in transporting growing media, materials, and equipment;
5) Not used for heavy industry or noxious purposes, this could compromise the health and safety of farmers and food grown on such structures.

Using these criteria, we identified 5,227 private buildings with a total area of 2,703 acres, and 474 public buildings with a total area of 376 acres. Of these buildings, 1,271 have a roof area of over 25,000 ft^2, equal to over half an acre. Other factors, which need to consider when determining whether a roof is suitable for agriculture, include roof materials and condition, roof access and egress, and sun exposure. The City University of New York's NYC Solar Map shows that 66.4 percent of buildings are suitable for solar panels (NYC Solar Map, 2011), indicating adequate sun exposure, but this figure includes sloped roofs as well. The focus on larger roof areas also increases the chance that such rooftops will have adequate sunlight for agriculture, and the industrial neighborhoods in which they are concentrated are largely uniform with respect to building height (minimizing the extent to which adjacent buildings cast shadows on the roofs). Figure 1.4 reveals clusters of potentially suitable roofs in the Greenpoint, Brooklyn, and the Maspeth and Long Island City neighborhoods of Queens, which is one of the most promising areas in the nation for rooftop agriculture. Additional areas with potential include Gowanus, Sunset Park, and East New York in Brooklyn, and Port Morris and Mott Haven in the Bronx. These estimates of the amount of rooftop space that would be suitable for agriculture are fairly conservative given the restrictive criteria – many roofs that are not included in these figures could potentially be used; the purpose of this analysis is to determine how much rooftop area is most suited for farming. As with other types of sites, accurate evaluation of suitability would take place on a case-by-case basis; supermarkets, for example, which would seem to be an ideal place for the location of a rooftop farm or greenhouse often present a challenge due to the large number of refrigeration vents and other protrusions on the roof. The structural requirements of an open-air rooftop farm are different from those of a greenhouse as well; while the former generally imposes an evenly distributed load, a greenhouse will typically involve point loads, which must either be aligned with the existing structural system or be otherwise distributed.

Figure 1.4. Potential Rooftop Farming in NYC.



Data sources: UDL; New York City Department of Information Technology and Telecommunications (2009); New York City Department of City Planning (2010)

1.3.9 Site Distribution

As evident from the maps of potential ground-based and rooftop sites in NYC, the wide variety of urban fabric typologies calls for a corresponding diversity of approaches to urban agriculture. Certain areas, such as Midtown Manhattan, offer few opportunities for space. Other neighborhoods, such as the areas in Brooklyn and the South Bronx mentioned in the Vacant Land description, have large concentrations of small vacant lots that could be organized into clusters or networks of farms and gardens sharing resources and equipment. Such networks would allow for food production from these areas to be aggregated for distribution and sale in stores, CSAs, farmers markets, or for donation to food pantries, and would allow for maximization of resources. Other areas, particularly in Staten Island, have large areas of vacant land that could be used for more conventional types of farms, while many parts of eastern and southern Queens, characterized by single family houses, are well suited for backyard food production. Other neighborhoods are particularly suited for rooftop farming.

Sunlight can be an issue for small lots in densely developed areas and is a common condition in NYC. A more thorough assessment of site suitability would include an analysis of how many of NYC's vacant lots are completely or largely overshadowed by tall buildings. Tree shade can also be a challenge, as many otherwise suitable sites are shaded by tree canopy. An analysis of urban tree canopy in NYC found that 44,509 acres, or 24 percent, of the total land area is covered by urban tree canopy, while 45 percent of open space and 41 percent of vacant land is covered by trees (Grove *et al.,* 2006). Our vacant land availability analysis excluded many large forested areas, but smaller lots or areas that are only partially wooded are included. Urban trees provide important environmental and health benefits, and the city is actively working to increase urban tree cover with such programs as the MillionTreesNYC program. Building and tree shade are limiting factors on crop types and yields, and on heavily shaded sites farming and gardening would have to be limited to shade-loving plants such as certain varieties of berries. As far as slope is concerned, NYC is a relatively flat city, especially compared with many urban areas in the West, and most of the steepest areas lie within the city's parks. While there are sites where slope and consequent soil erosion could be an issue for farming, they are rare.

1.3.10 Peri-urban agriculture

In addition to the land area and rooftop space potential for agriculture in the five boroughs, there is considerable opportunity for increasing food cultivation in the suburban region surrounding NYC. The New York City Metropolitan Statistical Area (NYC MSA), as defined by the U.S. Office of Management and Budget, includes 23 counties in three states, with a population of over 18 million. This area encompasses a wide variety of landscape types, and includes heavily urbanized areas as well as farmland. There are number of counties where agricultural activity is well established, such as in Hunterdon and Sussex Counties in New Jersey. Using land cover data derived from the National Oceanic and Atmospheric Association's Coastal Change Analysis Program (C-CAP), we determined that in 2006, there were a total of 394,253 acres of agricultural land (including cropland and pastureland) in the NYC MSA, or 9.2 percent of the total land area (as compared to 1,494,101 acres of urbanized developed land). Small to medium-scale farming is the dominant form of agricultural activity in this peri-urban area, which benefits from the close proximity to large concentrations of consumers, but is challenged by land availability and costs. For that reason, focus tends to be on higher value products; average market value of products sold per farmland acre in the region was $1,610 in 2007, as compared to an average of $616 per acre in New York State as a whole (USDA Census of Agriculture, 2007). There are also challenges with loss of active farmland – only 368,884 acres of the total agricultural land in the NYC MSA was actively being farmed in 2007 – a decrease of almost 14 percent from 1997, with some counties such as Rockland and Bergen losing close to 60 percent of active farmland during that ten-year period. While the region experienced large areas of farmland loss due to development for much of the 20th century, in the decades from 1990s through the 2000s that trend has slowed significantly. In each of the counties, only a fraction of a percent of farmland was lost to urbanization in this region. Instead, it appears that agricultural land is going out of production due to other economic challenges associated with farming. As indicated by the discrepancy between agricultural land as defined by National Land Cover Database (derived from remote sensing from satellite imagery) and farmland statistics from the USDA Census of Agriculture, which is based on acres in active farmland as reported by farmers themselves. While this is an indicator of the difficulty of ensuring the economic viability of small-scale farming, it also means that if distribution and marketing barriers are overcome, there remains some underutilized agricultural land in the region. Given the wide diversity of land use in the area, it perhaps is useful to distinguish between the counties directly adjacent to the five boroughs – Westchester, Rockland, and Nassau in New York, Bergen, Hudson, Union, and Middlesex in New Jersey – and the remainder of the region. Even in this heavily developed, suburban area, there are 36,403 acres of agricultural land, or 3.6 percent of the total land area.

1.4. Alternative Agricultural Practices

1.4.1 Soil-based Agriculture

Most urban farms are located on previously vacant, underused, or otherwise undeveloped lots. While soil-based urban food production involves many of the same challenges faced by conventional rural farming, in that weather, pests, and other environmental factors will affect the quantity and quality of what is grown, urban farming involves many unique considerations as well. Land is more difficult to obtain, and costs more whether leased or owned. Leases, where they do exist, tend to be of shorter duration. Additionally, soil quality and contamination is more likely to be a consideration in urban areas.

Soil-based food production can take place on a variety of different sites, as described in Section 1.3. Most of the food production in NYC takes place in community gardens, which are grassroots institutions with varying degrees of organization. Some community gardens are dedicated to decorative or landscape gardening, although over 80 percent of community gardens grow food (Gittleman, 2010). They can be loosely organized, divided into individual plots with different individuals deciding what they wish to grow (as is the case with NYC's largest community garden, the 3.25 acre Floyd Bennet Gardens). If more deliberate in their goals, some have organized coalitions and many grow enough food to feed not only their members but neighbors and members of the wider community as well. While most community gardens are non-commercial, some individual gardens or garden coalitions (such as the La Familia Verde Coalition in the Bronx) have developed CSA programs or operate farmers markets.

While there are over 1,000 community gardens in NYC, most people familiar with the issue would identify between 15 and 30 "farms," depending on the definition of the term (Figure 1.5). Criteria for a label on the map include, over 2,000 ft^2 of growing area and a focus on growing food for consumption by people other than the farmers/gardeners, whether through retail or donation. The USDA Census of Agriculture defines a farm as "any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold during the census year" (USDA Census of Agriculture, 2007), a definition that would include many community gardens as well. Most of NYC's farms and community gardens are in the neighborhoods of East New York, Brownsville, Crown Heights, Bedford-Stuyvesant, and Bushwick in Brooklyn, the Lower East Side and East and Central Harlem in Manhattan, and Morrisania, Claremont Village, East Tremont, and Belmont in the Bronx. There is a clear relationship between concentrations of community gardens and farms in NYC and income levels, which is because many of the gardens were established with the help of Community Development Block Grants that can only be used in low-income areas. Additionally, lower income areas have more vacant lots, have less access to fresh food retail and thus greater need for urban agriculture, and that internal and external community development resources and engagement are more concentrated in these areas.

Some gardens and farms are have incorporated as non-profit organizations that farm on city-owned or donated land, such as Added Value, which operates on a Department of Parks and Recreation Site in Red Hook, Brooklyn, and recently started a farm on city-owned land on Governor's Island. These farms often run CSA programs or farmers markets. BK Farmyards is developing a disbursed but organized network of sites, which collectively supply enough food to support a CSA, and is pursuing a creative approach to the challenge of space for farming in the city.

There are a number of different approaches to ground-level food production applicable to urban farming, though few are unique to urban environments. Given that many urban farmers are engaged in the activity at least partially out of concerns regarding the environmental and health impacts of conventional agriculture, most urban food production would meet or exceed organic standards, although few urban farms are certified organic. The cost and inconvenience of organic certification is as much a deterrent as is increasing skepticism among some farmers regarding the relevance of the organic label, particularly as it applies to urban agriculture. Of course, even without the application of synthetic fertilizers and pesticides, there are issues of potential soil contamination or air pollution to contend with and consider before certifying any urban farm as organic. There are other farming approaches that are increasingly being applied in the urban setting that seek to "go beyond" organic by adopting a more holistic approach to agriculture that emphasizes the integration of biotic and human systems. These include permaculture and biodynamic farming, which are approaches emphasizing symbiotic relationships between crop cultivation and "natural" climatic and hydrological processes that minimize external inputs and develop self-sustaining systems. (There are differences between the biodynamic and permaculture approaches, specifically in that permaculture has a greater emphasis on incorporating human settlements, while the philosopher Rudolph Steiner developed biodynamics, and thus includes a metaphysical component, which places it beyond the scope of this report.) An example of a technology that developed in accordance with the principles of permaculture is the Folkewall, or living wall, which is consists of a hollow concrete structure filled with a porous material and compartments on either side for plants. The structure is designed to filter greywater, which percolates through the wall and is absorbed by the plant roots, while growing food or other plants. To our knowledge, such a system for food crops at an appreciable scale in an urban setting has not been tested, although the concept is similar to hydroponics.

While many urban farmers are influenced by of the principles of permaculture (irrespective of whether they identify with the term itself), it is a challenge to put into practice in urban settings given that human habitation is considered one of the seven zones necessary for a fully functioning system. Instead, permaculture practitioners often approach urban agriculture as a small step towards integrating these disparate environments.

The health of the soil is one of the primary factors contributing to the success or failure of ground-based food production. Soil quality and contamination is a critical issue for all ground-based urban farms in NYC as elsewhere. Given the long history of human habitation and activity in most parts of NYC, it is assumed the soils are contaminated unless proven otherwise. Figure 1.6 shows existing NYC DEP Environmental Remediation sites (including brownfield cleanup, environmental restoration, voluntary cleanup, and state superfund sites) and the two more extensively contaminated EPA Superfund sites (New York State Department of Environmental Conservation, 2008). This is by no means a complete picture of soil contamination in the city; there are likely many areas that warrant the brownfield designation with a more comprehensive soil testing program. Brownfields are properties deemed contaminated due to previous on-site commercial or industrial activity. Such sites are often abandoned, idle, or under-utilized, although in some cases they remain active. Superfund sites are areas designated as uncontrolled hazardous waste sites by the EPA, which assumes oversight over cleanup. NYC has called for the creation of a pilot community garden on a remediated brownfield site, and will assist in designing protective measures to be used in reclaiming more brownfields as community gardens (The City of New York, 2011). On heavily contaminated sites, however, remediation may be a long-term process, and food production may not be advisable for many years. Assessments of suitability for food production relative to soil contamination must proceed on a case-by-case basis.

Figure 1.5. Existing Farms in NYC.

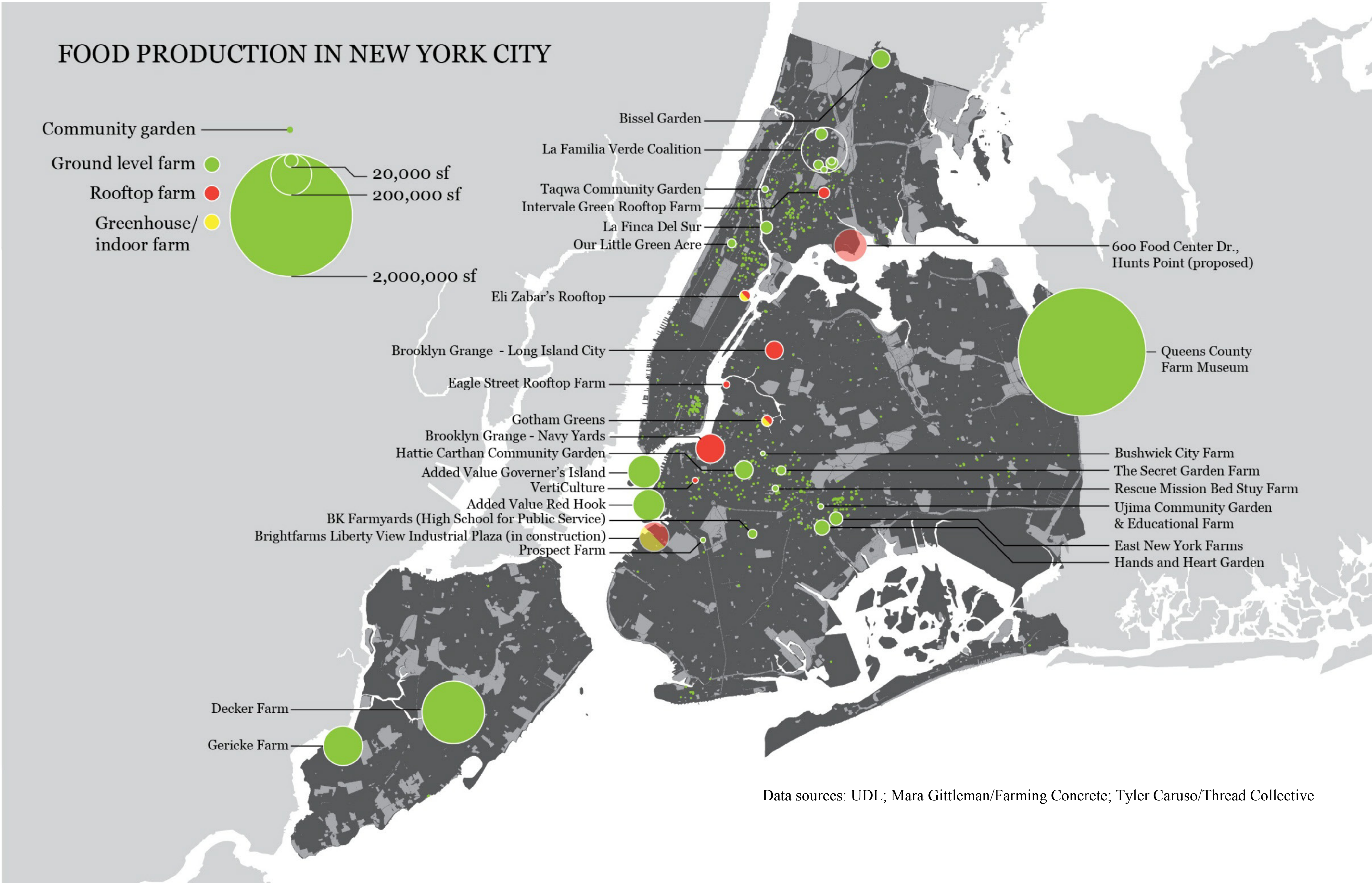
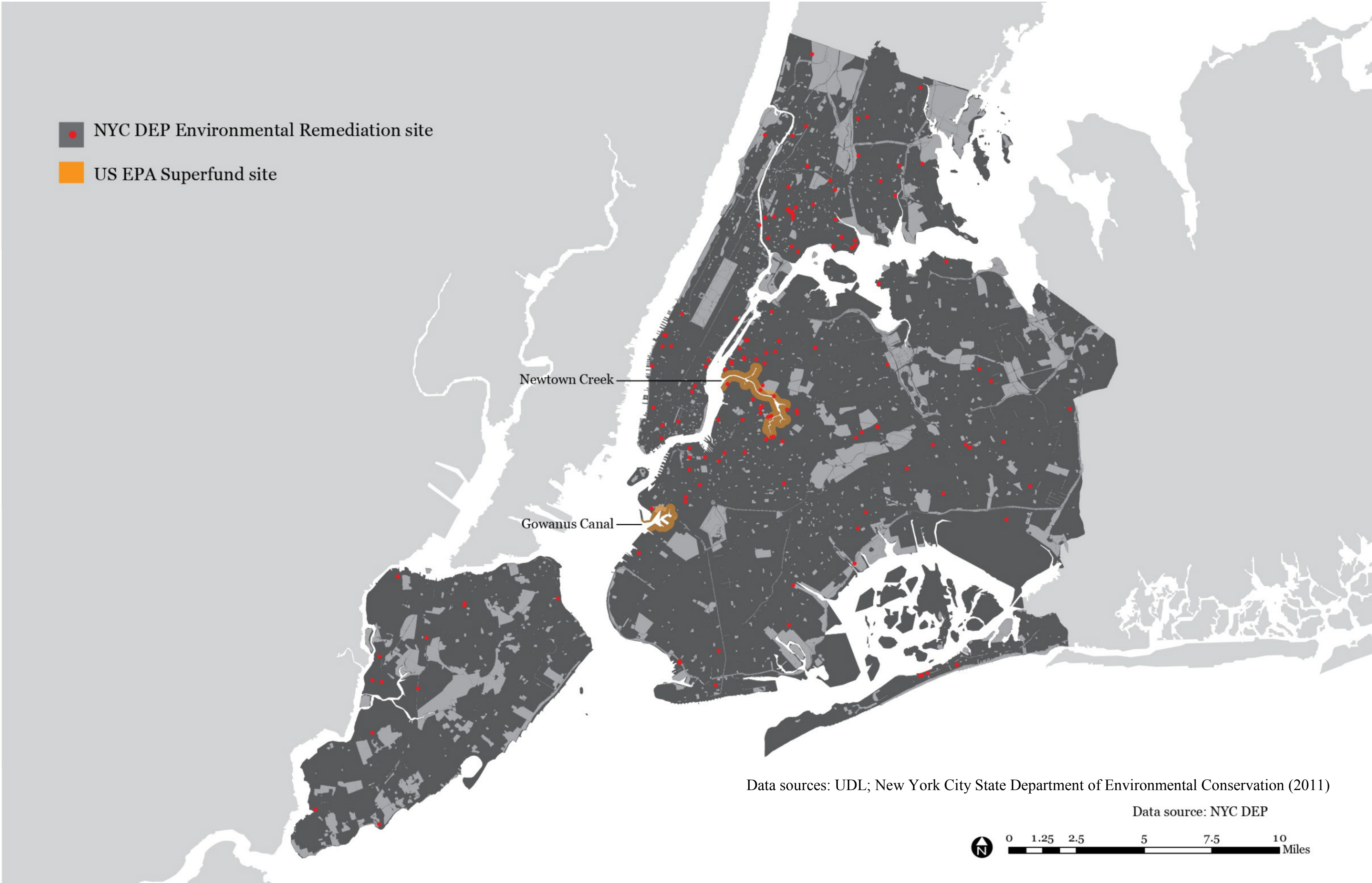


Figure 1.6. Environmental Remediation Sites in NYC.



1.4.2 Rooftop Agriculture

The land constraints inherent to urban areas have led to the development of alternative methods of farming in urban areas, most notably rooftop farming. Manufacturing districts in NYC are highly suited for rooftop agriculture, due to the number of large flat roofs combined with high land values, high density, and relatively little vacant land (discouraging on-the-ground farming). Other favorable factors include a high degree of demand and interest in local foods, high levels of available capital, proximity to schools and institutions of higher education (for research support), and proximity to transportation and distribution infrastructure.

Rooftop farming presents its own set of challenges in that environmental conditions are often more harsh, even just a few stories above ground, with stronger winds and sun exposure. Choosing the right soil for rooftop farming is a complex endeavor, with nutrient contents, weight, permeability and porosity all being important factors, not to mention the challenge of getting all the soil onto a rooftop, which often requires a crane. Most rooftop farmers use Rooflite® (or an equivalent), which is a lightweight growing medium formulated specifically for green roofs. Although Rooflite® manufactures media that are designed for intensive green roofs and even rooftop farming, there is little research on the attendant nutrient quality of the produce grown in such media. Growing media depths are often limited by the structural capacity of the roof (soil for rooftop farming can weigh up to 50 pounds or more per square foot when saturated), meaning that only relatively shallow root crops will grow and often at lower yields than with ground-based agriculture. In cases where structural capacity is an issue, constructing an additional structural support system designed to channel loads directly onto the load-bearing areas of the roof is an option; alternately, the use of containers on rooftops to concentrate loads directly over structural supports also allows for small areas to grow deeper-root crops. It is necessary to replenish soil nutrients often, and the combination of shallow soil and higher wind speeds makes installing trellises or tunnels very difficult. An advantage of rooftop soils is a greater degree of control over potential contaminants, allowing effective management of soil composition and nutrients. Given the relative novelty of rooftop agriculture however, there are uncertainties regarding the long-term capacity of the growing media to support food production, and accumulation of contaminants is a concern. It is possible that, unlike conventional soils, rooftop growing media will have to be replaced over time. Given the constraints, relatively large expanses are necessary to make growing food on rooftops in a commercially viable enterprise. Opinions vary on how much area for commercial viability is needed; Eagle Street Rooftop Farm has only 6,000 ft^2 of growing area, though other rooftop farmers have indicated that an acre (c. 44,000 ft^2) or more is ideal. Rooftop farmers in NYC have successfully grown a wide variety of produce and are in the process of gathering valuable information on which crops do well in these unique environments.

The greatest issue for aspiring rooftop farmers is gaining affordable access to existing rooftop space. Property owners may be reluctant to assume potential liability or maintenance concerns, and rooftop farming is still seen by many as a relatively untested enterprise. There remains a good deal of uncertainty regarding the long-term viability of rooftop farming; landlords do not want hundreds of tons of growing medium on their roof and no one to farm it. There are also substantial costs associated with starting a rooftop farm (the 40,000 ft^2 Brooklyn Grange rooftop farm, for example, required approximately $200,000 of start-up capital). There are inherent advantages to landlords as well, including the potential energy savings provided by a green roof, the potential to receive rental revenue from a previously unoccupied space, and the additional distinction that comes from having a rooftop farm on a building that can lead to increased demand for units within the building. The existing rooftop farms in the city are acting as a critical "proof of concept" that could pave the way for wider acceptance on the part of property owners and are establishing important precedents for the streamlining of the permitting process at the Department of Buildings.

Stormwater runoff and CSO into NYC's waterways are one of the city's most intractable environmental challenges, and green roofs are a form of "green infrastructure" that the city has identified as a means of mitigating this problem. Green roofs can reduce CSO events in two ways. Detention occurs as soil absorbs the rainwater and eventually released once reaching the saturation point, with the delay between a period of heavy rainfall and the eventual release of the water into the sewer system. This has the benefit of decreasing the overload on the treatment systems, which result in CSOs. Retention occurs as the soil absorbs the rainwater and eventually evaporates directly from the soil or through the process of evapotranspiration in plants. Retained water never makes its way into the sewage system. As far as detention is concerned, rooftop farms could have an advantage over conventional green roofs in that deeper growing medium is required: at least six inches, and often up to ten inches of soil or other medium, as opposed to two to four inches for sedum plantings. Deeper soils generally detain more water; however, fact that food crops generally need to be irrigated, and soil that is partially saturated is less effective at absorbing additional stormwater could offset by this benefit. Detention rates vary widely depending on the type of growing medium used, although there are indications that soils which are replenished through composting have increased hydraulic conductivity (The City of New York, 2010). Another factor is the degree of pre-saturation, which is determined by time between rainfall events and the amount of irrigation used for the crops. Farmers are by necessity well attuned to the weather forecast and will make decisions on when to irrigate accordingly; however, it is difficult to account for the vagaries of behavior and varying crop needs when estimating the stormwater mitigation potential of agricultural green roofs. As for retention, the differences between agricultural and conventional green roofs are equally complex. Again, deeper soil is assumed to have greater retention capacity. There is some indication that retention decreases beyond a certain depth (NYC DEP, 2010) possibly because solar energy penetration decreases and deeper soils dry more slowly than shallow ones. This research was performed on roofs planted with shallow-root sedum, whereas deeper root food crops could offset this factor with increased water transpiration from the bottom of the soil layer. The greater surface area of food crops compared to sedums could also increase evapotranspiration rates, at least during the growing season, while during the winter months conventional green roofs would likely perform better.

Decreasing stormwater runoff from rooftops has benefits beyond reducing CSO incidence. Contaminants from roofscapes and streetscapes can make their way into the city's waterways regardless of CSO events, either because sewage treatment plants are not designed to treat such pollutants or from direct runoff. Green roofs can reduce pollutant runoff in water through filtration and biological uptake of nutrients (Köhler and Schmidt, 2003); however, green roofs have the potential to leach contaminants into runoff as well. Intensive composting operations, whether on rooftops or at ground level, have the potential to leach nitrogen into waterways if runoff is not well managed. More research is necessary to investigate the composition and potential contaminants from various rooftop growing media.

1.4.3 Controlled Environment Agriculture

Growing food in greenhouses is another approach to urban agriculture that has attracted increased interest, particularly given New York State's relatively short growing season. Greenhouses range from simple structures used for seedling germination in the spring to complex environments engineered to provide optimal growing conditions year-round. This latter approach, called Controlled Environment Agriculture (CEA), often uses hydroponic growing methods. In urban areas, CEA often takes place on rooftops, not only because of the familiar challenge of land and land costs but also because greenhouses require ample access to sunlight, a condition which is difficult to find at ground-level in dense urban areas. In NYC, examples of urban CEA include Gotham Greens in Greenpoint, Brooklyn and Eli Zabar's rooftop farm on the East Side of Manhattan. The DCP recently passed a zoning text amendment that excludes rooftop greenhouses atop commercial buildings from Floor-to-Area Ratio (FAR) limits, provided they meet certain criteria. The criteria require buildings that do not contain residences or other sleeping accommodations, the greenhouses only grow plants, and the facility includes a rainwater collection and reuse system.

The cost of artificially heating a greenhouse during the winter months can be prohibitive; the capture of waste heat from the host building could defray such costs. Although not conclusively demonstrated, it is thought that locating the greenhouse on top of a building (particularly a poorly insulated one) would offset passive heat loss. The summer months present the opposite problem, when adequate ventilation is necessary to prevent overheating. There may be energy benefits to locating greenhouses on top of buildings housing activities that generate heat, such as kitchens and bakeries. Nevertheless, there are significant practical challenges to integrating greenhouse climate control systems with the HVAC system of a pre-existing building, and this approach is rarely taken. Rather, it may be that the best opportunities for climate system integration to lie with new projects where the original design incorporates such functions . The difficulty and necessity of maintaining optimal growing temperatures mean that CEA climate control systems are frequently automated. Despite these challenges, greenhouse agriculture, and CEA in particular, has some advantages which make it well adapted for urban environments. As mentioned, rooftop greenhouses can make use of waste heat from buildings, can produce food year-round, and are well suited to vegetables such as greens for which freshness (and therefore proximity to retail and consumers) is especially important. Hydroponic growing systems can achieve much higher yields per square foot of growing area than other methods, and operated year-round, a significant advantage in New York State's climate.

Given the costs associated with construction and operation, the commercial viability of rooftop hydroponic greenhouses depends on the production of high-value products, such as micro-greens or tomatoes, that can be sold at a premium, especially in the off-season. Proponents of CEA cite increased yields, extended growing season, and greater control of nutrient levels and pests as reasons to believe that such techniques will be critical to feeding urban populations, especially given concerns over soil nutrient depletion, desertification, water shortages, and climate change. Others point to the high material and energy costs of CEA to argue that they are unlikely to be a substantial source of food in the future. The potential for increased energy efficiency and productivity of rooftop greenhouses in urban areas that can take advantage of waste heat may alter the equation in favor of CEA. Technological advances in the field combined with a rising demand for fresh produce year-round are contributing to an increasingly fertile environment for urban greenhouses. (For a more in-depth discussion of the energy inputs in CEA systems, see Section 2 of this report.)

Hydroponic vegetable production can also be integrated with fish farming in a system called "aquaponics," in which waste from fish is processed to provide some of the nutrients for growing vegetables, which in turn filter the water for the fish. In fully integrated aquaponic systems, composted vegetable cuttings create food for worms, which are fed to the fish. This system requires precise calibration (and often lots of trial and error to perfect), and is especially attractive to some advocates of urban farming who are interested in community self-sufficiency because of its combination of animal and vegetable cultivation. While aquaponics has been around for a while, the development of recent larger-scale operations at in Milwaukee (including the non-profit Growing Power and the for-profit Sweet Water Organics) have led to renewed interest in the potential for aquaponics in urban areas. In NYC, a greenhouse with an aquaponic system was completed on the roof of the Manhattan School for Children. Aquaculture specialist Philson Warner, who started by raising fish in a basement in the Bronx, now directs aquaponics programs at the Food and Finance High School in Manhattan and on Rikers Island. Although aquaponic systems are relatively low-tech, they do require a fair amount of equipment and continual maintenance, and the risk of disease in this closed system must be carefully managed. The system requires little external inputs, provides a range of key nutrients (including protein), and can be adapted to a variety of urban spaces (though, unlike indoor aquaculture, sunlight or other strong light sources are needed for the hydroponic component). This is an attractive option for those who are committed to the idea of producing a wider range of foods in urban areas. Nevertheless, aquaponics is a relatively new approach and it will take some time to establish the long-term robustness of such systems.

A more speculative approach to CEA that has been receiving attention over the past several years is "vertical farming," a concept championed by Columbia University professor Dickson Despommier. He posits that due to soil nutrient depletion and the ecological impacts of industrial farming systems, it would be preferable to grow large volumes of food in skyscrapers designed specifically for that purpose. This concept has not yet demonstrated its feasibility from an economic or environmental perspective, given the large amounts of energy necessary to operate such a system. Unlike in a greenhouse, plants grown in a vertical skyscraper-type structure would have limited sunlight and would require high levels of artificial light, with the consequent CO_2 emissions from generating power for these lights.

1.4.4 Economic Considerations

Only a handful of existing urban farms in NYC are for-profit ventures, and nearly all rely to some extent on volunteer labor or free or below-market rate rent and as such are difficult to compare with traditional businesses. Exceptions include Gotham Greens, which operates a large rooftop greenhouse in Greenpoint. In general, due to the relative novelty of urban agriculture in NYC, the economic viability of the existing farms has yet to be conclusively demonstrated. Projects in other locales, including Philadelphia (Urban Partners, 2007) have indicated that profitability in urban settings in the U.S. is possible, although the replicability of these examples is uncertain. Practitioners have adopted creative means of generating revenue and maintaining their operations, such as direct marketing and sales at the farm, through CSA programs, to restaurants and grocery stores, as well as grants and fees received for educational and youth development programs, job training, and leasing of land to other farmers and gardeners. Some farms have exclusive arrangements with local restaurants wherein a portion of the farm is dedicated to products requested by them. These arrangements, in which chefs can request limited quantities of specific products, are an example of the types of opportunities that are afforded by both close physical proximity and personal relationships to the consumer/buyer that is an advantage of urban farming. Additional programming on farms, including tours, special events, and merchandise, are all emerging manifestations of urban agritourism and contribute to the bottom line of farms such as Brooklyn Grange. From the evidence, it seems likely that demonstrably profitable business models will be developed by a new generation of farmers, many of whom are interested in developing businesses that are economically sustainable.

1.5. Scale and organization of horticulture systems

There are three primary factors which differentiate urban agriculture from rural agriculture: scale of production, which is limited by the land or rooftop availability in urban areas; methods of product distribution, which are based on close proximity between the farm and the retailer or consumer; and, to a lesser extent, what is defined as the "emotional" proximity between farmer and consumer, which could lead to differences in consumption habits. In this section, we focus on these differences between large-scale and small-scale agricultural systems and the extent to which these factors could have substantial impacts. Additionally, within each of these segments of the food value-chain we attempt to define the distinguishing features for further developing a methodology to assess these differences.

1.5.1 Production

As mentioned above, the scale of agricultural production in urban areas is generally much smaller than on rural farms, for obvious reasons. The average farm size in the U.S. is 418 acres, while small- and mid-scale farms characterize the Northeast. Average farm size in New York State is 197 acres–this includes the entire area of the farm property, which is larger than the area under cultivation (USDA Census of Agriculture, 2007). In NYC, by contrast, the mean size of the “farms” shown in Figure 1.5 is 0.34 acres (not including the community gardens). This substantial scale difference necessarily results in divergent approaches to production, with larger scale, capital intensive agricultural systems characterized by commodity crops such as corn or soybean, and smaller scale, labor intensive systems more likely to adopt polycultural techniques.

The tools with which the agricultural sector in developed countries have increased productivity throughout the last century are mechanization and the application of agrochemicals (Woodhouse, 2010) and advances in plant and animal breeding. Regardless of location-specific economic conditions, such as land and labor availability, and differences in the development of the agricultural sector in different regions, modern industrial agricultural systems have converged in practice. Agriculture–especially in the U.S.–is now characterized by large-scale monocultures, reliant on Haber-Bosch fixated nitrogen and other industrially produced nutrients and pesticides. This evolution in the agricultural industry has resulted in declining real food prices throughout the 20th century (Figure 1.7). The recent increase in food prices can in part, be attributed to price increases of fossil fuels, which function as both direct inputs (e.g., diesel fuel and electricity) and indirect inputs (e.g., synthetic fertilizers) into the agricultural sector.

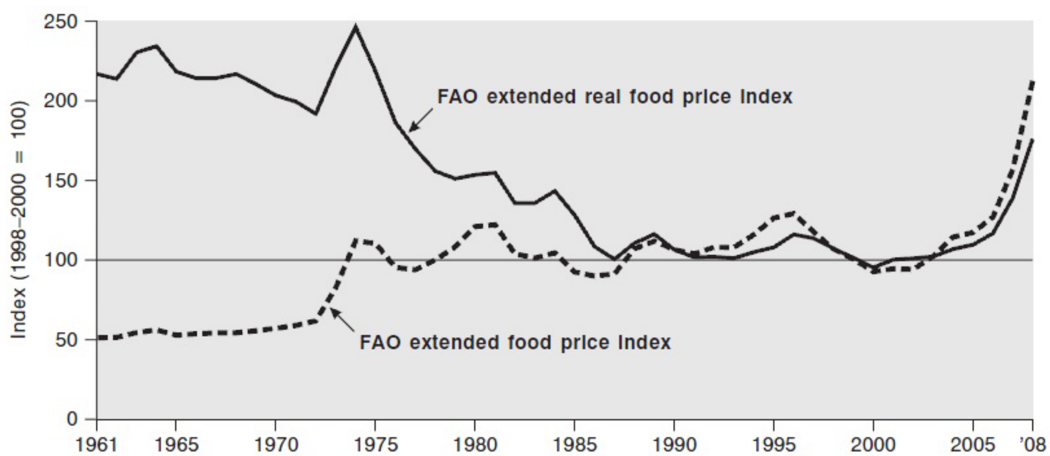


Figure 1.7. FAO food price index (real and nominal) as presented in Woodhouse (2010).

Reliance on specialized machinery and equipment for tilling, sowing, irrigating, fertilizing, and harvesting, large-scale farming favored a transition to monoculture production. While there are significant advantages to the efficiencies of scale inherent in such agricultural practices, there are also drawbacks. The benefits of plant diversity in agriculture are well documented, and include herbivore suppression (Letourneau *et al.,* 2010), decreased pesticide use, increased resistance to disease and blight, and increased soil integrity, which may decrease the need for synthetic fertilizers (Altieri *et al.,*1983; Thrupp, 2000). Furthermore, planting a variety of crops in close proximity typically leads to increased land productivity compared with crops grown in monocultures. While polycultures can theoretically be cultivated at any scale, managing a diversity of crops involves greater reliance on manual labor, and from a practical perspective thus tends to be practiced on smaller plot areas. A commonly used metric to describe the productivity of intercropping is the land equivalent ratio (LER). Denoting the yield of a crop *i* in a certain polyculture by YP_i and the yield of the same crop grown in a monoculture by YM_i the LER is defined as

$$\mathrm{LER} = \sum_i \frac{YP_i}{YM_i},$$

in which the sum covers all crops grown in the same area. Cultures with a LER>1 exhibit greater productivity than monocultures and are sometimes called "biologically over-yielding", (Schultz et al., 1982) A few examples of biologically over-yielding crop combinations are carrots + lettuce (Neto, et al., 2010), the Native American staples corn + beans + pumpkin (Mt. Pleasant and Burt, 2010) and cucumbers + tomatoes (Schultz et al., 1982). The latter study also introduces a metric comparing the economic output in polycultures compared to monocultures, called 'relative value total' (RVT). Denoting the dollar value of the yield of crop *i* grown in a polyculture by VP_i and the highest value crop grown in a monoculture by *VM*, the RVT is defined as

$$\mathrm{RVT} = \frac{1}{VM}\sum_i YP_i.$$

A polyculture with an RVT<1 would produce less value than a monoculture of only the highest value crop. If, on the other hand RVT>1, the polyculture produces more value than any monoculture could on the same piece of land. Altieri (2009) argues that most small-scale intercropping farms exhibit this kind of 'economic over-yielding.'

The ability to grow crops in polycultures is probably the most important opportunity embodied in small-scale farming. Of course, the substitution of mechanical for manual labor has economic implications as well, with labor a major component of overall value chain costs. For this reason, small-scale, particularly urban agriculture tend to involve high-value vegetable products. Even with a focus on such products, the higher costs of land and labor remain a significant challenge to the viability of urban and peri-urban farming (see Section 1.4.4 for a more in-depth discussion of the economic challenges of urban agriculture).

Of the five inputs required to sustain plant growth−sunlight, CO_2, water, nutrients, and labor−the availability of the first two is independent of plot size. If both water and nutrients are supplied uniformly over the growing area, losses through evaporation and infiltration are also proportional to area and therefore independent of scale. Losses through surface runoff, on the other hand, occur through the perimeter, which would preference larger plot sizes to reduce their relative importance. Studies on small-scale farming (Altieri, 1999; Kiers *et al.,* 2008) do however indicate that resource use efficiencies on smaller farms can be equivalent to those on larger farms, suggesting that scale is not a significant determinant regarding losses through surface runoff. It is likely that agricultural practices, to a much greater extent than unit scale, determine efficiencies in agricultural systems. As previously mentioned, intercropping can reduce the need for synthetic fertilizers (as well as pesticides) and better maintain the integrity of the soil.

With small-scale farms typically being more labor intensive and less dependent on energy intensive equipment, some researchers have argued that small-scale farms have a lower energy profile in the production stage (Pelletier, *et al.,* 2011). Also, as a secondary effect, small-scale farms are typically family operated, which to some observers correlates with stronger incentives to increase resource-use efficiency (Hatirli *et al.,* 2006; Kiers *et al.,* 2008), although the extent to which this effect is a factor in urban farms, which are typically not family operated but often are characterized by strong social and community ties, is unclear.

1.5.2 Distribution

For the overall food system in the U.S., energy inputs are concentrated in the production and consumption stages of the value chain, with relatively less required for the transportation and distribution phases. Canning et al. (2010) found that five percent of total energy expenditures on food are attributable to transportation; however, this figure is quite different for fruits and vegetables. Compared to meat, grain, and processed foods, fresh fruits and vegetables which make up the bulk of urban food production, have a significantly larger portion of energy penalties concentrated in the food handling and transportation stages of the value chain (see Table 1.1). Albright and de Villiers (2008) found that for select fruit and vegetable products, transportation energy generally exceeded that of production energy for crops grown in New York State.

Table 1.1. Energy consumption (trillion Btu) in different sections of the vegetable food chain in the U.S. (Cuéllar and Webber, 2010). Food handling incorporates activities such as refrigeration, cooking and packaging, whereas food processing covers milling, cutting and other food preparation operations.

Production	Transportation	Food handling	Food processing	Total
53.5	407	935	178	1580

The dominant model of intensive, large-scale agriculture involves transporting food long distances between the various components of the value chain, including aggregation/warehousing, processing, wholesale, and retail. A 1998 study found that produce at the Chicago Terminal Market traveled an average of 1,518 miles from farm to market (Pirog *et al.,* 2001). This figure is a 22 percent increase from 1981, and given the greater distance from the nation's primary produce growing regions in the West, it is likely that the produce in NYC's Hunts Point Market has traveled farther on average. A 2008 study, for example, found that a sample of five products (spinach, strawberries, tomato, lettuce, and apples) traveled an average of 2,200 to 3,000 miles to get to markets in New York State (Albright and de Villiers, 2008). There are many reasons that this figure has increased, including year-round demand for seasonal products, increasing globalization of trade, and lower land costs (land, soil, and climate conditions are often more conducive to farming) in rural areas farther from cities in the Northeast.

One of the primary benefits of small-scale, urban, and peri-urban farming, by contrast, is proximity to consumers. While it is true that shipping produce across the country by rail can be more energy efficient than an equivalent amount transported regionally in small trucks, the very small distances between farm and market for urban agriculture may result in less energy use for transportation, storage and refrigeration. Regardless of origin, food transported into the city must ultimately contend with the "last mile" problem, which significantly decreases total transportation efficiency; in that regard, products grown in or near the city are not unique. Also, a leaner distribution network could reduce the penalties associated with food handling. With a total annual vegetable consumption of 62.2 million tons (Cuéllar and Webber, 2010), the average specific energy consumption by food handling and transportation is estimated at 15 kBtu/kg and 6.5 kBtu/kg, respectively, using Table 1.1.

While these values can be used as benchmarks in case-specific analyses, a more relevant metric is the energy embedded per unit of food delivered. This metric would to a greater extent incorporate losses throughout the system and their relative importance on the overall energy budget. For instance, the numbers provided by Cuéllar and Webber (2010) suggest that the specific energy per kilogram vegetable product produced is 860 Btu/kg (53.5 trillion Btu/62.2 million tons). However roughly 20 percent of the produce is left on the field, meaning that the specific energy per unit delivered (in the production stage) is higher, 1.10 kBtu/kg. Anticipating reduced losses as well as food-miles traveled, applying such a metric would presumably reveal substantial benefits in favor of local farming with leaner distribution networks. Indeed, for selected crops, suppliers outside of New York State used on average two and a half times as much energy as local producers to get their products to market in New York State, and when differential shrinkage is factored into the calculation, the energy inputs for non-New York State suppliers is on average three to four times higher (Albright and de Villiers, 2008).

According to Kantor, *et al.* (1997) the average food product is handled 32 times before reaching the consumer in the supermarket. Each time vegetables are handled there is a risk of rupturing the skin leading to spoilage by microbial growth. The smaller volumes and greater diversity of products that are characteristic of small-scale farming combined with close proximity to a large consumer base, enables the grower to market products to consumers directly, thereby reducing the number of intermediaries. Indeed, a survey performed by the USDA (Low and Vogel, 2011) revealed that almost 80 percent of the sales channels for small farms are direct-to-consumer. Even with one middleman, such as a farmers market, the losses in the distribution chain could potentially be reduced and the requirements on packaging might be relaxed, which in turn might lead to lower costs. In order to bypass many of the steps in the distribution chain, direct marketing, which capitalizes on small-scale polycultural production approaches such as CSA, may be the most efficient way to take advantage of urban growing conditions. Without such mechanisms, urban farmers may have difficulties bringing small volumes to market. While proximity to population centers and points of consumption might carry the benefits mentioned above, it may also increase the opportunity costs of the land used for farming, especially in urban areas. These costs are significant and need to be carefully considered.

1.5.3 Consumption

One of the oft-cited merits of localized food systems is the potential for increased familiarity with the realities of food production and healthy eating associated with consumer-farmer interactions and the cultural visibility of urban farms. While it would be difficult to assess the true impacts of such attitudinal shifts, there may be a real energy value in increasing the "emotional proximity" between producer and consumer if it would result in lower food losses.

The report 'Global Food Losses and Food Waste' (FAO, 2011) identifies food losses within five system boundaries in the food supply chain: agricultural production, post-harvest handling and storage, processing, distribution and consumption. The largest losses for fruit and vegetables occur in the production and consumption stages (Figure 1.8). One of the primary causes for loss occurring on the farm is attributed to consumer behavior, as strict quality standards imposed by retailers lead to the discarding of produce with cosmetic deficiencies, which is otherwise edible. If local farming can reduce the mental distance between consumer and producer, these standards could perhaps be relaxed and less produce wasted. This effect would likely be small and difficult to confirm, but anecdotal comparisons suggest that cosmetic standards are less stringent for produce sold at farmers markets or through CSA programs compared to conventional retail.

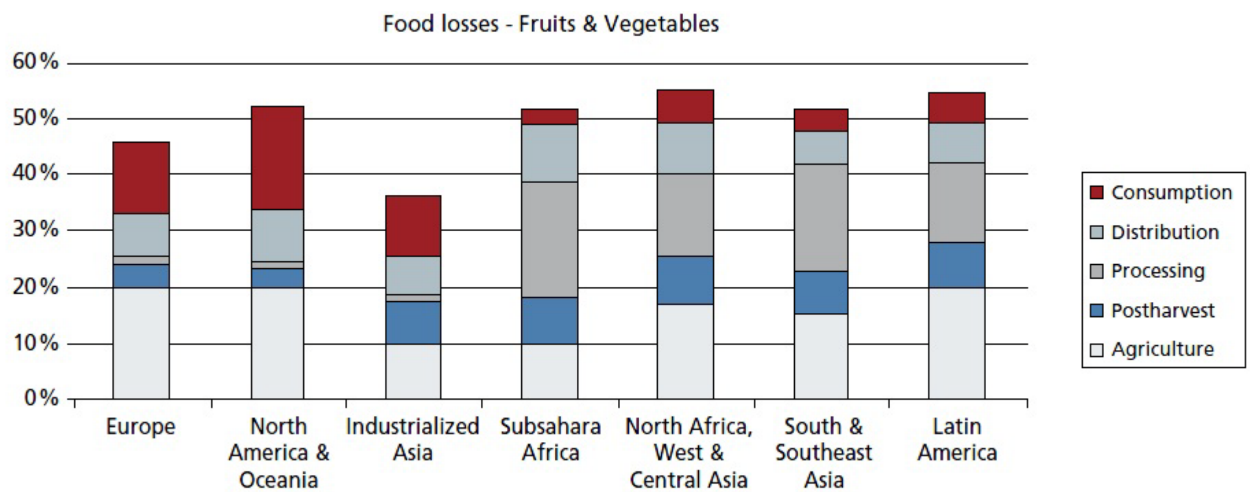


Figure 1.8. Food Losses for Fruits and Vegetables (FAO, 2011).

1.6. Ability of small-scale agriculture practices to contribute to regional food supply in urban areas

Although there may be efficiencies associated with small-scale food production as outlined in Section 1.5, the degree to which urban agriculture could contribute to the food needs of large urban populations remains an open question. Addressing this question requires a greater understanding of potential yields for fruit and vegetable crops in urban settings, for which comprehensive data is not available. While we do our best to estimate the potential capacity of NYC to grow food, it is important to note that for many urban farmers in particular, maximizing yields is one of many priorities.

Given what many assume to be an inhospitable climate, a surprising variety of crops is grown in NYC's community gardens and farms. Nevertheless, there is a limit to what can be grown, and ideal crops for NYC include those that are climate-suitable, high yield, high value, harvested multiple times during the season, do well in marginal soils, and spoil quickly (giving a competitive advantage to freshness and therefore localized production). Some urban farmers are making use of greenhouses for germination and hoop houses or tunnels to extend the season, particularly for leafy greens, which do well in colder weather and grow well into November. Rooftop greenhouses are capable of producing food year-round, often passively or actively benefiting from waste heat. There are unexplored opportunities for capturing waste heat from adjacent buildings for ground-level greenhouses as well. It is possible that the growing season is slightly longer and range of crops that can be grown is broader due to the urban heat island effect and the influence of climate change. The USDA recently updated its plant hardiness zone map, and changed NYC's zone from 6b to 7b (average minimum winter temperature of five to ten degrees). Greater climate variability, increased incidence of climate extremes, and potential geographic spread of pests make the impacts of climate change on agriculture in the Northeast difficult to predict.

Vegetables represent the bulk of agricultural activity in the city. Many urban farmers focus production on vegetables because they are well suited to urban conditions and contribute to increased access to fresh, healthy foods. This is especially important for low-income communities that often lack access to such foods (particularly vegetables). Fruit cultivation is also taking place in the city. Berries are a high value crop well suited to urban conditions; blueberries, a hardy native plant, could do particularly well on rooftops. Fruit trees are more of a challenge, at least on a commercial scale. Despite doing well in sub-par urban soils, fruit trees require lots of space and maintenance. Pests are also a problem for many fruit trees and they often have to be sprayed to control insects. Despite these limitations, there are sites where having trees as opposed to ground crops could be an advantage, and at least one organization, Newtown Pippin, is working to increase the number of apple trees in the city. Other cities such as Philadelphia and Calgary also have programs dedicated to fruit tree cultivation.

Figure 1.9 shows what type of demand might be expected for various products, and which products are primarily purchased fresh as opposed to frozen or otherwise processed. Demand for dark green and orange vegetables (as designated by the USDA) would benefit from the freshness factor, and although consumed in far lesser quantities than starchy vegetables, the latter are less suitable for urban environments. Furthermore, USDA dietary recommendations call for an increase in dark green and orange vegetable consumption and a decrease in starchy vegetable consumption. Leafy greens are generally high yield, are some of the most nutritious vegetables, often must be consumed fresh, and can be very profitable in urban settings. Berries are high value products – they also spoil quickly, which can be a challenge, although they are ideal for value-added processing, and often do well in difficult environments such as rooftops. Many vegetable farmers in both rural and urban areas have found that a sound business strategy is to focus on greens in the spring and fall, and tomatoes during the height of the summer (while also growing an assortment of other vegetables), to ensure continuous production of high value crops.

Figure 1.9. Estimated NYC Fruit and Vegetable Demand.

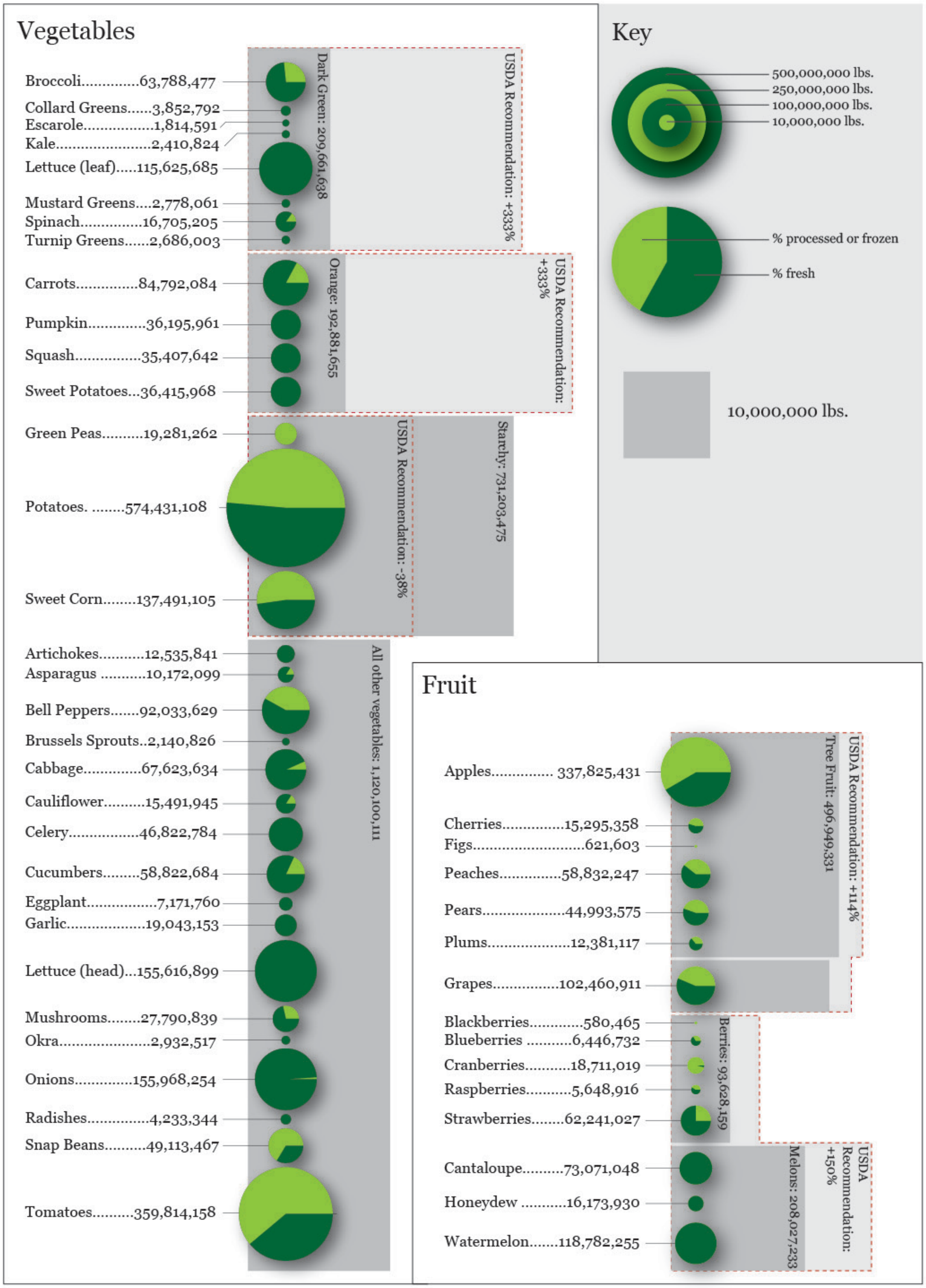


Figure 1.9 features estimates in pounds of the amount of fruits and vegetables needed to supply NYC's retailers annually. Figures are derived from the U.S. Food Market Estimator tool (Leopold Center for Sustainable Agriculture, 2008), which uses the USDA-ERS Food Availability Data System, an annual estimate of the amounts of hundreds of food items available at a per capita rate for human consumption in the U.S. The volume estimates indicate the amount of each food type delivered to NYC retailers to supply the population of the city, and accounts for food spoilage in stores and in the home. Estimates do not take into account food spoilage on farms and en route to retail, as it is likely food produced on urban farms sold locally would have a lower spoilage rate than food transported from great distances. The percentage of each food type sold fresh versus processed or frozen is from the same source, with figures from "fresh" category of the "Sub-product" field for the volume of fresh product sold, and all other categories within that field for the volume of processed or frozen product sold. The percent by which each fruit and vegetable type falls short of or exceeds USDA consumption recommendations was determined by comparing existing consumption figures with those outlined by in the USDA ERS report by Buzby *et al.* (2006).

It is difficult to reliably predict yields because there are many variables to consider, including environmental conditions (soil, water, sunlight, etc.), growing techniques, and crop types. The question of how much land area is needed to feed a certain population therefore, has no straightforward answer, and estimates require a large number of assumptions. When discussing urban agriculture, the problem becomes even more complex, as the USDA collects the most reliable yield data and is applicable primarily to large-scale farming techniques, which differ significantly from those used in urban agriculture. Not as much research has focused on potential yields in urban and peri-urban settings where agricultural activity tends to be small-scale and labor intensive. Urban farmers use highly intensive growing methods to maximize the productivity of small plots of soil, and for select crops yields per area can be much higher than with conventional farming. This is because the limited available space is often used more efficiently (rows can be planted close together as there is no need to accommodate tractors and other machinery, and vertical space is cultivated through the use of trellises, cages, or other supports), and several harvests of multiple complementary crops are possible through intercropping. It is difficult to evaluate yields of polyculture compared to conventional monoculture production, given that the former approach uses the same areas for different crops at different times during the growing season, whereas yields data is typically expressed as weight (or volume), area and year. There is nothing inherently "urban" about these intensive growing methods, other than that they are often employed as a means of taking full advantage of limited growing areas, and are as likely to be found on small-scale farms in peri-urban or rural areas as in cities.

There are factors that can depress expected yields in urban areas as well. One of these is poor soil quality, which is prevalent on urban lots, although many urban farmers are actively managing soil fertility through composting and other means, while others are growing in raised beds. There are air quality issues to consider as well; studies on the effect of ozone (O_3) on plant growth have determined that concentrations found in NYC could have a negative effect on crop yields (Heagle, 1989). Baseline summer average O_3 levels in NYC in 2005-2007 were approximately 0.045 ppm (NYC Department of Health and Human Hygiene, 2010). Estimated yield losses at these concentrations range from 1 to 14 percent, depending on the concentration of ozone; tomatoes, for example, researchers estimated a loss of five percent at an ozone concentration of 0.04 ppm and 10 percent at a concentration of 0.05 ppm (Heagle, 1989). On the other hand, the elevated levels of CO_2 found in NYC's atmosphere have been shown to promote plant growth (Searle *et al.,* 2011).

There are factors other than growing area against which to measure yields, such as yields per unit of (water, fertilizer, or fuel) input. Smaller-scale, intensive growing techniques could be more productive because the application of inputs tends to be more targeted compared to conventional agriculture. If, however, yields are measured against such factors as labor or operational costs the results may be quite different, due to the relatively higher costs of land, labor, and services in urban areas. An additional consideration is the fact that, as described in Section 1.5, over 30 percent of fruit and vegetable production is lost prior to reaching the consumer. Differences between small- and large-scale farming systems that could have an impact on losses would have to be factored into an assessment of the capacity of smaller-scale systems to feed urban populations, given that the ultimate measure of food access is retail availability (and affordability), not production yields.

A number of studies have evaluated crop yields from urban farming, and specific methods for maximizing productivity on small plots have been developed, including the Small-Plot Intensive (SPIN) farming approach (essentially a distillation of widely-practiced techniques packaged and sold for accessible replicability). In NYC, the *Farming Concrete* project has mapped all of the city's community gardens and is in the process of measuring how much food they produce. Preliminary results indicate that 87,690 pounds of vegetables were grown on 71,950 ft^2 in 67 gardens in 2010, which comes out to just over 1.2 lbs/ft^2 of produce (Gittleman, 2010). Dominic Vitiello and other researchers have been involved in an ongoing project to measure fruit and vegetable production in community gardens in Philadelphia. Vitiello found that on some plots farmers were able to grow up to 1.4 lbs/ft^2 of vegetables, a very high yield given the small size of plots (under 5,000 ft^2). Farmers were producing primarily tomatoes, a highly productive vertically cultivated crop (Vitiello and Nairn, 2009). Other, more anecdotal sources indicate that average yields of around 0.5 lbs/ft^2 of a diverse array of vegetables can be achieved over larger areas using intensive production methods. Brooklyn Grange rooftop farm achieved yields of approximately 0.3 lbs/ft^2 during its first year of operation (which started late into the growing season) and hopes to increase to 0.5 $lbs./ft^2$ with some adjustments in their second year (personal communication with Ben Flanner, Head Farmer & Co-founder, Brooklyn Grange). An assessment of urban agricultural potential in Oakland, CA, used a figure of ten tons/acre for expected yields (McClintock and Cooper, 2009), which amounts to 0.46 lbs/ft^2. Several studies, including an evaluation of the production potential of vacant land in Detroit (Colasanti *et al.,* 2010), cite the book *How to Grow More Vegetables* by John Jeavons (2006), which has been a touchstone for farmers and gardeners practicing "biointensive" growing methods (organic, high-yield farming with a focus on improving soil quality). The book includes extensive charts documenting yields for a large variety of crops, and is a very comprehensive and useful resource for urban farmers. Its utility for researchers is limited; however, as all data is derived from one site in California, but the broad range of food (and fiber) crops included in the book makes for a useful reference.

Table 1.2 shows average yields, estimates of NYC retail purchases by crop, and land requirements for conventionally grown vegetables and fruits groups (USDA NASS, 2010a). Conventional yields are compared to the “low biointensive” yields, described by Jeavons (2006) as sub-optimal soil conditions or climate, which is a fair characterization of NYC’s growing conditions (figures are derived by averaging yields of all listed crops). Again, it must be stressed that these comparisons should not be given undue weight, given that different geographic regions are being compared and the conventional yields have a large sample size while the biointensive yields, while derived from long-term experiments, have a very small sample size. Based on anecdotal evidence, most farmers growing in New York State’s climate can expect yields somewhere between the USDA figures and the “biointensive low” figures, with more experienced growers approaching and perhaps exceeding the higher ranges of yields projected by Jeavons. Table 1.2 shows that dark green vegetables have some of the highest yields, averaging about 0.5 lb/ft^2 for conventional production and almost a 1.0 lb/ft^2 for biointensive production. The “other” vegetables category includes cabbage and celery, which are very high yield vegetables as well. These figures do not reflect CEA or hydroponic growing methods, for which yields can be orders of magnitude higher, as the environmental and nutrient mix is carefully calibrated for maximum production, plants can be arranged to optimize space efficiency, and production can take place year-round. Products that are particularly well suited for hydroponic production include tomatoes, cucumbers, lettuce, strawberries, and melons. While there is no comprehensive resource for yields of hydroponic crops, various studies conducted by agricultural extension offices confirm consistently higher yields per acre for greenhouse and hydroponic as compared to conventional production. Tomatoes, for example, average greenhouse yields in the U.S. are 484 metric tons per hectare (or 432,000 lbs/acre), while fresh field tomato yields are 32 metric tons per hectare (or 29,000 lbs/acre) (Cook and Calvin, 2005).

Table 1.2. Food Crop Average Yields and Estimated Acreage for NYC Retail.

	Food Group	USDA / conventional average yields (lbs./ ft^2)	"Bio-intensive low" average yields (lbs./ ft^2)	Estimated NYC annual retail (x 1,000,000 lbs.)	Estimated land area needed USDA / conventional average yields (acres)*	Estimated land area needed "bio-intensive low" average yields (acres)*
Vegetables	**Dark Green** Broccoli, collard greens, escarole, kale, lettuce (leaf), mustard greens, spinach, turnip greens	0.49	0.95	210	10,983	8,671
	Orange Carrots, pumpkin, squash, sweet potatoes	0.43	0.70	193	10,321	6,323
	Dry Beans & Peas Dry edible beans, dry peas and lentils, lima beans	0.03	0.07	62	46,804	34,490
	Starchy Green peas, potatoes, sweet corn	0.35	0.47	731	35,672	33,525
	Other Artichokes, asparagus, bell peppers, brussel sprouts, cabbage, cauliflower, celery, cucumbers, eggplant, garlic, lettuce (head), okra, onions, radishes, snap beans, tomatoes, misc. vegetables	0.60	0.83	1,120	56,140	32,406

Fruit	**Tree Fruit** Apples, cherries, figs, peaches, pears, plums	0.28	0.32	470	27,132	24,311
	Grapes	0.20	0.45	102	11,761	5,227
	Berries Blackberries, blueberries, cranberries, raspberries, strawberries	0.20	0.23	94	25,940	7,635
	Melons Cantaloupe, honeydew, watermelon	0.52	0.50	208	9,462	9,551
	Warm weather / Citrus Apricots, avocados, bananas, dates, grapefruit, kiwi, lemons, limes, mangoes, olives, oranges, papaya, pineapple, tangerines	N/A	N/A	886	N/A	N/A
Total				4,076	232,215	162,139

* Total acres is derived by multiplying yields and estimated consumption separately for each fruit and vegetable listed (not the averages), and therefore does not correspond to the average figures listed in the table.

1.7. Acreage and distribution of land needed to provide for a given number of people

Understanding the capacity of urban agriculture to feed urban populations hinges on estimates of how much food can be grown in a given area. This is a critical question in that the viability of urban agriculture and its political and cultural support is at least somewhat dependent on perceptions of whether it can have a significant impact on food availability and security in urban areas.

Table 1.2 includes estimates of the amount of each fruit and vegetable category needed to supply NYC's retailers annually (as shown in Figure 1.9). The volume estimates indicate the amount of each food type delivered to NYC retailers to supply the population (8,175,133 as of the 2010 census), and accounts for food spoilage in stores and in the home. Estimates do not take into account food spoilage on farms and en route to retail, as it is likely food produced on urban farms sold locally would have a lower spoilage rate than food transported from great distances (the energy implications of this issue will be explored in greater depth in Section 2). According to these estimates, the most-consumed vegetables are potatoes (approximately 574 million lbs. to retail), tomatoes (360 million lbs.) and onions and head lettuce (155 million lbs. each), while the most-consumed fruits are oranges (413 million lbs.), apples (338 million lbs.), and bananas (208 million lbs.). Figures include processed foods such as sauces and juice.

The "estimated land area" columns are calculated using the yields information and the supply data, and indicate that between 162,000 and 232,000 acres are needed to supply NYC's stores with fruits and vegetables. This does not include the approximately 886 million lbs. of tropical or warm-weather fruit consumed annually by New Yorkers which cannot be grown locally (these warm-weather products represent 64 percent of total fruit consumption by weight and 24 percent of combined total fruit and vegetable consumption by weight). These areas represent actual areas under cultivation; for example, a typical one-acre plot that includes paths between beds, access, equipment storage, etc., may have 0.7 acres under cultivation. For reference, NYC's five boroughs encompass about 195,000 acres (154,000 acres excluding streets and water bodies). Converting all of the potentially suitable vacant land in the city (estimated at 4,984 acres; see Section 1.3) to agriculture with an average growing area of 70 percent of lot area could supply the produce needs of between 103,000 and 160,000 people (depending on whether conventional or biointensive yield figures are used). While this is a substantial number, it is not sufficient to feed the entire city. Although there is much more land potentially available than just vacant lots, it is clear that NYC cannot be self-sufficient in supplying its fruit and vegetable needs (much less all foods). As discussed in Section 1.6, there is additional agricultural land available in the peri-urban counties surrounding NYC. Between 46 and 71 percent of the 368,884 acres of active farmland in the counties comprising the NYC MSA would be sufficient to supply the fruit and vegetable needs of NYC residents, (excluding warm-weather fruit, and depending on whether using USDA or alternative yield figures are used). If the total population of 18,897,109 of the NYC MSA is taken into account, the agricultural land of the region could support between 58 and 89 percent of the of the region's fruit and vegetable needs, were that land dedicated entirely to production for local markets. These figures demonstrate the theoretical possibility of supplying a substantial portion of the city's fruit and vegetable needs locally, if not within city limits. For specific high value, healthy crops suited to urban farming, the prospects of localized production are eminently feasible from the perspective of land availability (the economic challenges are of course another matter). Crops such as beans and potatoes need a great deal of land area and are not particularly well suited to small-scale, urban production, whereas crops such as leafy greens and tomatoes may be grown in large quantities in urban areas. For dark green vegetables, for example, it is estimated that 8,671 acres are needed to supply NYC using biointensive growing methods and that the approximately 360 million pounds of tomatoes consumed annually by New Yorkers could be grown on 8,260 acres. To grow these vegetables hydroponically, considerably less area is needed.

A variety of data sources was used to create Table 1.2. Fruits and vegetables were divided into different groups based on USDA consumption recommendations to consolidate information. USDA / Conventional Average Yields were derived from USDA National Agricultural Statistics Service data (USDA NASS, 2010 a –d; USDA NASS, 2011) and USDA Economic Research Service (USDA ERS, 1996). Yields per acre were averaged for each commodity from 2007−2009 using New York State statistics when available; otherwise, NJ, PA or national statistics were used. Figures were averaged for each fruit and vegetable group and divided by 43,560 to determine yields per square foot.

“Bio-intensive Low” Average Yields were derived from the lowest numbers in the “Possible GROW BIOINTENSIVE Yield in Pounds per 100-square foot planting” column in the charts on pages 86−126 in Jeavons (2006). All of this data is from one site, and the figures therefore do not necessarily reflect expected yields for urban agriculture in NYC; however, the limited information available on yields in Northeastern cities indicates that this lower range of the biointensive yields is within the range of what can be expected using intensive growing methods in this area. Figures were averaged for each fruit and vegetable group and divided by 100 to determine yields per square foot.

The “Estimated NYC annual retail” column includes estimates rounded to the nearest million pounds of the amount of each fruit and vegetable type needed to supply NYC’s retailers annually. Figures are derived from the U.S. Food Market Estimator tool described in Section 1.6 (Leopold Center for Sustainable Agriculture, 2008). The figures are extrapolated from national consumption figures and do not reflect actual consumption in NYC; they are, however, the best estimates available across a wide variety of food types. While there would certainly be large variations in consumption at a neighborhood level, per capita consumption figures for the entire city are unlikely to be radically different from those for national consumption. Volume estimates indicate the amount of each food type delivered to NYC retailers to supply the population of the city, and accounts for food spoilage in stores and in the home. Estimates do not take into account food spoilage on farms and en route to retail, as it is likely food produced on urban farms sold locally would have a lower spoilage rate than food transported from great distances.

The figures in the “Estimated land area needed for cultivation” columns were derived by multiplying the average yields (conventional or biointensive) by the estimated retail volume (lbs.) separately for each product in each vegetable and fruit group and then adding the results together for each group. The acreage figures are therefore different (and more accurate) from the result of multiplying average yields per food group by total estimated retail volume by food group. In a few cases, yield data for a specific crop was unavailable and average yields for the fruit or vegetable group for that crop were then used to determine acreage needed for that crop.

Urban agriculture is already contributing to improved food security in NYC. Community gardens across the city are providing food to members and supplying local food banks with their produce. Researchers at the Farming Concrete project estimated that 87,690 lbs. of vegetables were grown on 67 gardens of the city's hundreds of community gardens in 2010 (Gittleman, 2010). Urban farms such as Added Value Red Hook and East New York Farms have CSA programs offering produce from their farms, while Eagle Street Rooftop Farm has a CSA, which is supplemented with produce from a farmer in the Hudson Valley (this may be the first CSA in the nation to be at least partially supplied by a rooftop farm). Farms and community gardens are also selling their produce at farmers markets, in some cases onsite (such as with Added Value Red Hook, East New York Farms, La Finca Del Sur, Hattie Carthan Community Garden, and others), and the City is partnering with Just Food to establish five more farmers markets at community gardens. Many of these farmers markets also host regional producers from outside the city. These examples provide evidence of how urban agriculture is acting as a catalyst for larger food system change by providing facilities and logistical support for regional producers to gain access to urban consumers. Many of these community farmers markets are in areas where conventional grocery stores are reluctant to locate due to concerns about neighborhood income levels and demand.

As discussed above, it is unlikely that by using current growing methods, NYC would be able to grow a large percentage of its fruit and vegetable needs; however, if the needs and resources of particular communities within the city are considered, a different picture arises. Many neighborhoods have a confluence of factors that make urban agriculture a particularly attractive and effective means of addressing multiple challenges. These include low access to healthy food retail, high prevalence of obesity and diabetes, low median income, and comparatively high availability of vacant or other available land. It is not a coincidence that these factors are correlated, and it is in these areas where urban agriculture could have the greatest impact on food security. Figure 1.10 shows the relationship between median income and vacant land in census block quintiles in the Bronx, Brooklyn, Manhattan, and Queens. Staten Island, which has relatively high income neighborhoods and a great deal of vacant land, was excluded from this analysis because its density, development patterns, and demography are more similar to surrounding suburban areas than to the other four boroughs. The chart demonstrates that areas with lower median income levels have more vacant land, with almost twice the percentage of vacant land (3.16%) and well over twice the number of vacant lots per acre (0.27) in the lowest income quintile as compared the highest quintile (1.65% and 0.12 lots per acre, respectively).

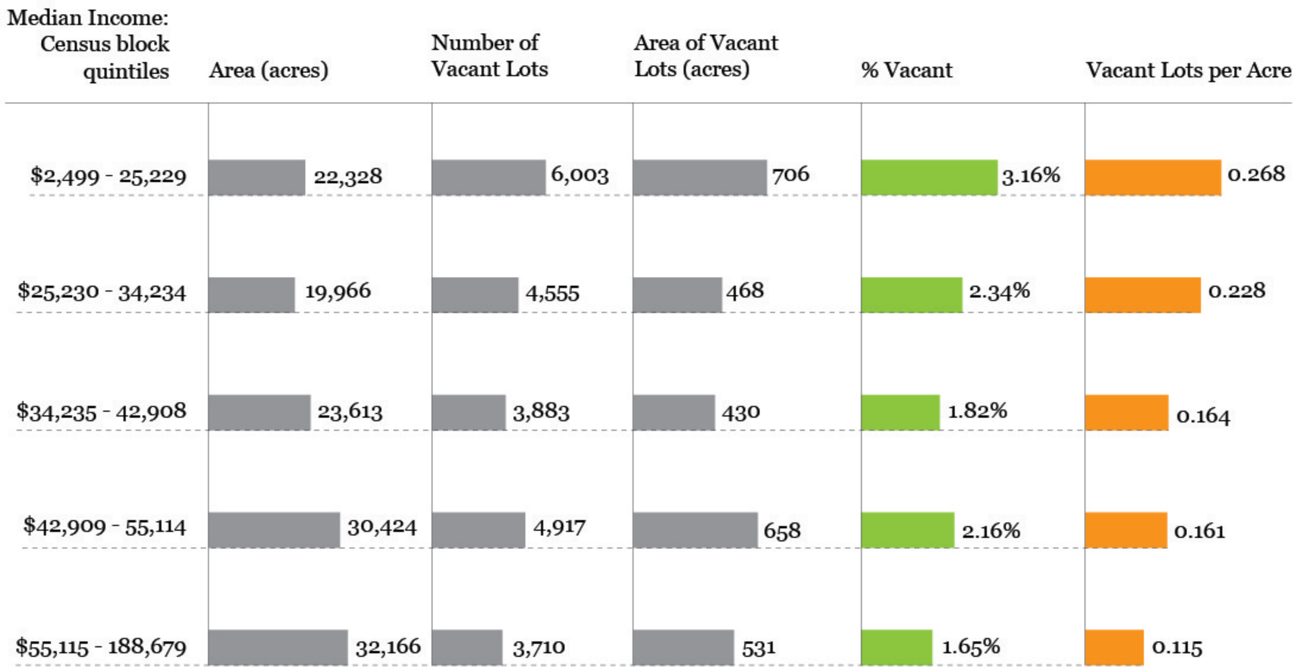


Figure 1.10. Vacant Land by Median Income Quintiles in the Bronx, Brooklyn, Manhattan, and Queens.

Neighborhoods fitting the pattern of inadequate healthy food access, high incidence of diet-related disease, and higher percentage of vacant land include East New York, Brownsville, Crown Heights, Bedford-Stuyvesant, and Bushwick in Brooklyn, the Lower East Side and East and Central Harlem in Manhattan, and Morrisania, Claremont Village, East Tremont, and Belmont in the Bronx, among others. These are neighborhoods where many community gardens signify community interest in and engagement with food production. In these neighborhoods, urban agriculture could improve fresh food availability. For example, Brooklyn Community district 16 (Brownsville) has 58 acres of vacant land. If that land is converted entirely to vegetable farming, it could produce as much as 45 percent of the district's 85,000 residents' annual supply of dark green vegetables (broccoli, collard greens, escarole, kale, lettuce leaf, mustard greens, spinach, and turnip greens; this estimate assumes an average lot coverage of 70 percent for growing area). This district also has an estimated 23 acres of green space on NYCHA property, as well 14 acres of surface parking – converting some of this area to farming or gardening could increase the availability of fresh produce even more. While it is unlikely that all or even a majority of this land will be used for farming, even a small increase in fresh food availability in these chronically underserved neighborhoods will have an impact on food security.

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Chapter Two. Analyses of Agricultural Techniques

This era is increasingly defined by energy price volatility and energy-related challenges to national security, from political instability in resource-rich regions to uncertainties concerning the long-term impacts of climate change. In this context, continued measurement and evaluation of the impacts of agriculture and food systems on energy use is critical. Adding to the complexity of such evaluations is that these systems are highly heterogeneous, making comparative assessments of various approaches to, and scales of, agricultural production and distribution all the more important.

The food system in the U.S. has undergone profound shifts in the past 50 years. These changes are characterized by increases in nutrient supplementation, advanced crop and pest management, and increased mechanization in agriculture that have collectively boosted yields by substantial margins. Increased globalization of trade has allowed for regional specialization and year-round availability of a wide variety of previously seasonal or exotic food crops. There has been a corresponding shift in retail and consumption, with the U.S. population spending an increasingly smaller portion of their income on food, while spending less time cooking and more money on processed and prepared foods and food eaten outside the home (USDA ERS, 2012). All of these changes have had significant impacts on energy use in the food system, with food-related energy flows accounting for over 80 percent of energy increases in the U.S. during the period from 1997 to 2002 (Canning *et al.,* 2010). About half of this increase is attributed to population change, while the rest is due to increasing mechanization in all components of the food system. As a result, food-related energy use grew from an estimated 14.4 percent of the national energy budget in 2002 to 15.7 percent in 2007.

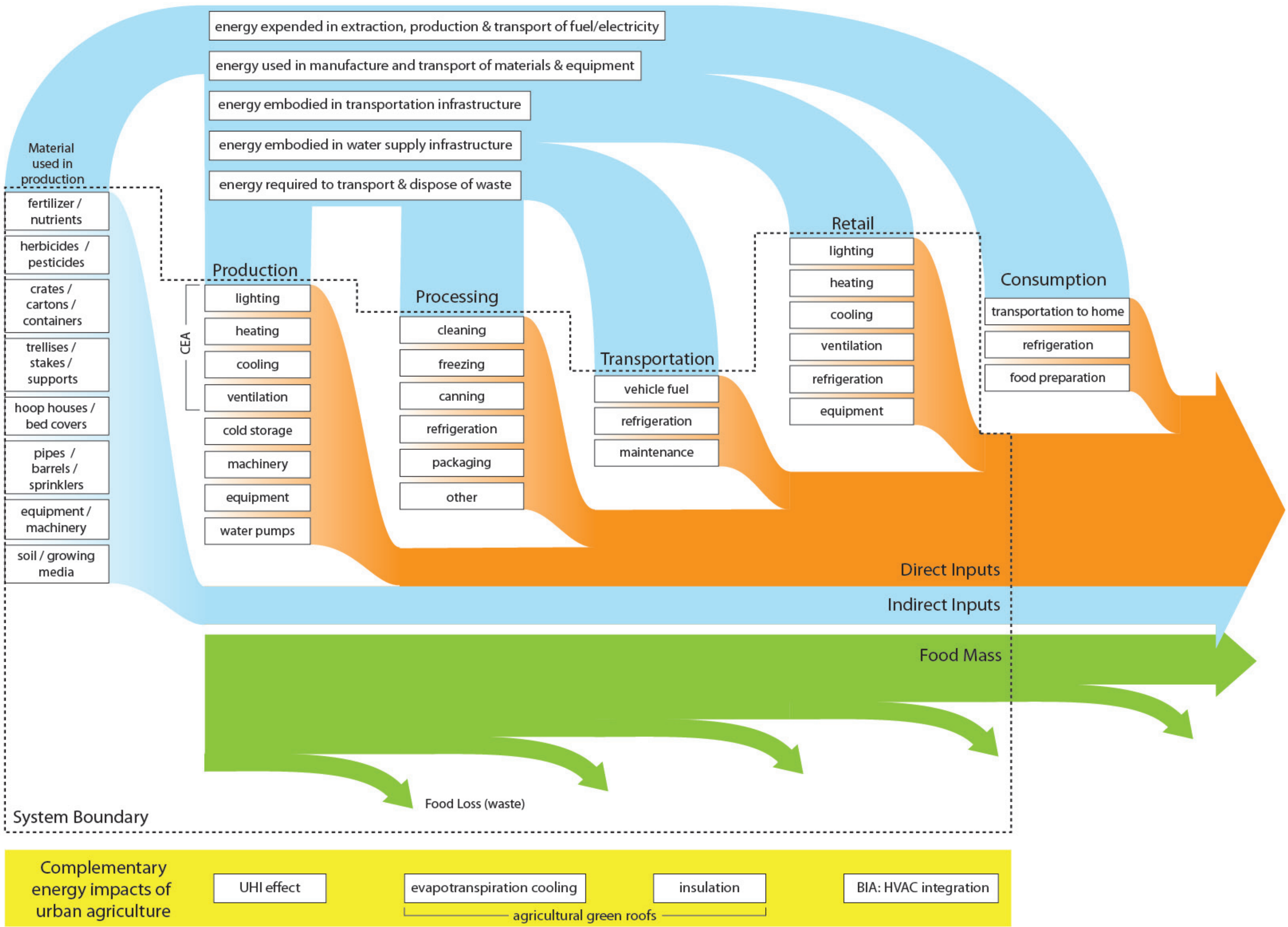
This same period has also witnessed the emergence of alternative trends at the smaller end of the production spectrum, with an increasing number of farms, particularly in the Northeast and the West Coast, turning to direct marketing. This trend, insofar as it eliminates one or more stages in the food distribution chain, represents a larger movement (albeit still small in comparison to the more prevalent shifts described above) towards de-industrialization and deconsolidation of the food system. The value of agricultural products marketed directly to consumers increased by 77 percent from 1992 to 2007, and direct marketing is especially prevalent in the Northeastern U.S. (Low and Vogel, 2011). There has been a corresponding increase in farmer’s markets in the U.S., with the number of farmer’s markets growing fourfold from 1994 to 2011 (USDA AMS, 2011). These types of activities are typically undertaken by small- to medium-scale producers as a means of capitalizing on more direct relationships to consumers made possible by geographic proximity to population concentrations. Such alternative value chains have also grown in part thanks to the perception that locally or regionally sourced food has environmental benefits because of lower transportation requirements and less resource-intensive methods of production. The accuracy of these assumptions is difficult to ascertain given the wide variety of production, processing, and transportation modes along the entire scale spectrum. The aim of this project is to address some of these questions – at least qualitatively – and to delineate the range of issues that must be studied in greater depth in order to establish best practices for energy use in small-scale urban and peri-urban farming.

2.1. Establish system boundaries.

The food system is highly complex and multivariate; it intersects and overlaps with other overarching networks, such as the energy and transportation grids, which form the infrastructural backbone of our industrialized society. To evaluate or compare performance within such systems, it is necessary to establish clear system boundaries within the life cycle of the products. The determination of what will be included in the life cycle analysis helps to isolate which specific factors are being compared, and as such is often the most important factor in the outcome of this type of research.

For the purposes of this study, we differentiate direct inputs into the system, indirect inputs, and complementary energy impacts (Figure 2.1). Direct inputs are materials, energy, or energy expending processes, which count as direct costs to entities within the food value chain, namely producers, processors, distributors, retailers, and consumers. Indirect inputs are materials, energy, or energy-expending processes that serve a broader range of interests than those strictly associated with the food system, and whose costs are either embedded in direct costs (e.g., the cost of energy expended in extraction and production of electricity is partially embedded in the price of electricity) or borne by the government or by society in the form of taxation (e.g., highway transportation infrastructure). Complementary energy impacts occur from operations associated with the food system (in this case, specifically from urban agriculture operations), but which may not directly affect the energy use or finances of these entities.

Figure 2.1. Conceptual Framework with System Boundaries. For the purposes of evaluating the implications of scale in agriculture on energy use, we propose including in the systems boundaries direct energy inputs through the retail stage of the distribution chain, as well as indirect energy embodied in the materials used in production, and comparing these to the mass of food purchased by consumers (to account for food loss along the chain).



The indirect inputs, which are part of the food system life cycle, include large-scale infrastructural systems that underlie all industrial activity. Energy is itself expended during the extraction, production, and transport of fuel and electricity, and the energy used by an entity therefore carries an energy penalty beyond what a usage meter reflects. The extent of this embodied energy use is highly dependent on the fuel type or if electricity is used (e.g., fuel for machinery vs. electrical energy), as well as geographic location. The energy grid in different parts of the nation is dependent on different types of generation sources. In NYC, for example, sources of electricity include natural gas (54%), nuclear power (30%), hydroelectric (9%), coal (6%) and fuel oil (1%) (The City of New York, 2011). Additionally, about seven percent of all electrical energy is lost during transmission (EIA, 2011a). Greenhouses are often heated during the winter months with propane; however, as described in Section 1.4.3, there is also the possibility of integrating a rooftop greenhouse climate system with that of the building on which it sits.

There is significant energy embodied in the infrastructure used to transport agricultural production materials and equipment, as well as for the transportation of food products; and, energy is required to manufacture and transport the materials and equipment used by all agricultural operations. The energy embodied in water supply infrastructure is of special significance to a comprehensive accounting of the life cycle of agricultural systems. Much of our produce comes from states with constrained water resources, particularly California. California is the nation's largest producer of both fruits and vegetables, with 51 percent of the nation's bearing acreage of fruit trees and 24 percent of harvested vegetable acres (USDA NASS, 2010 a–c). Water constrained regions rely on massive infrastructure to manage supply and irrigation. The same is true of many of the countries, which are major exporters of fruits and vegetables to the U.S., such as Mexico, which accounts for 64 percent of all vegetable imports (Huang and Huang, 2007). By contrast, New York State and the Northeast generally have ample rainfall. Furthermore, certain climate change projections indicate that the Northeast may expect increasing precipitation in the coming decades, while prolonged drought may afflict areas in the West (Mellilo and Peterson, 2009). Energy is also required to transport and dispose of waste as discussed in Section 1.5.2; smaller-scale agricultural systems may be able to reduce food losses throughout the value chain which in turn relieves energy penalties associated with waste handling.

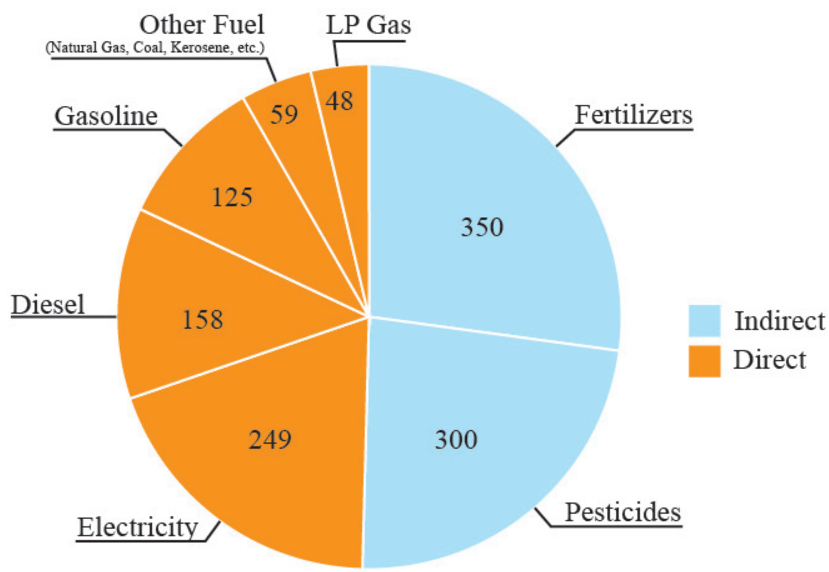
Cumulatively, these indirect, embodied infrastructural inputs may dwarf the direct energy inputs into the food system; however, they are not included as part of the life cycle analysis system boundary for the purposes of this study due primarily to the difficulty in quantifying these values. Total energy use in these highly complex systems is very difficult to assess, while estimating the relative portion of such inputs that support any one particular sector, such as agriculture (much less specific components of that sector, such as fruit and vegetable production) is a task beyond the scope of this study.

The energy used for the manufacture and transportation of farming materials and equipment constitutes an indirect energy input. Given that it is associated with specific goods and products, it is relatively easier to assess than the infrastructural inputs. The indirect energy input is also directly relevant to the issue of scale in agriculture and many urban and peri-urban farms make concerted efforts to minimize these inputs. For these reasons, on-farm material consumption should be included in any food system life-cycle analysis. The most energy-intensive farm inputs are synthetic fertilizer and pesticides. Fertilizer accounts for approximately one-third of all energy consumption attributed to crop production in the U.S., with nitrogen requiring high-energy inputs to produce (approximately 70,000 kJ per pound of nutrient) (Gellings and Parmenter, 2004). Certain fruits and vegetables, such as potatoes, tomatoes, and grapes, have the highest rates of nitrogen fertilization (as measured in pounds/acre) of any crop (Schnepf, 2004). Although pesticides represent a smaller portion of total energy use, pesticide production requires on average four to five times more energy per weight than production of nitrogen fertilizer, and is the most energy intensive on-farm material input (Ferraro, 2003). While there is no reason why scale of production should affect fertilizer or pesticide use per unit of area, in practice many small-scale farms in urban and peri-urban areas in the Northeast minimize (or in the case of organic farms, eliminate entirely) the use of synthetic compounds for nutrient supplementation or pest control. Other material used on farms includes trellises, stakes, and other supports; construction materials for hoop houses and bed covers; harvesting and packing material, including crates, cartons, and other containers; materials required for irrigation, including pipes, sprinklers, or if rainwater is collected, barrels, and other equipment, tools and machinery. Small-scale−particularly urban−farming tends to be less mechanized than larger-scale production, and there are likely to be lower energy costs associated with the manufacturing of heavy machinery. For many urban farms, there is the added factor of sites that either have unsuitable soil (contaminated or poor quality) or no soil (paved lots or rooftops), in which case soil, organic matter, or other growing media is needed. In some cases, when trucks transport soil onto the site, considerable energy is required. On rooftop farms or other applications where conventional soils would be too heavy, engineered growing media are used. The energy used in the manufacturing and transportation of such material can be significant – for example, Brooklyn Grange rooftop farm in Long Island City required about 600 tons of growing media, which was transported from Pennsylvania (personal communication with Ben Flanner for Brooklyn Grange, January 2011). This material is composed of shale and other lightweight mineral aggregates that must be quarried or mined, processed, then transported to a manufacturing facility, and supplemented with composted organic material. Trucks transport the resulting mixture to the farm.

Direct inputs in the life cycle for the food system can be assessed along the various stages of the food value chain, conventionally described as consisting of production, processing, transportation/distribution, retail, and consumption. As noted in Section 1, it is important to consider this entire system because some of the energy implications of scale differences in agricultural systems (indeed, perhaps the major implications) may be on components of the value chain other than production, such as processing and distribution.

While direct energy inputs in the on-farm production stage increased at an average rate of approximately one percent per year (EIA, 2002), inputs per unit of output continues to decline since peaking in the late 1970's. The decline is due primarily to increasing efficiency of production techniques and associated technology, and more targeted inputs of fertilizer and pesticides. Direct energy used on farms consists of diesel and gasoline used in vehicles, machinery and equipment (55% of total direct energy consumption); electricity for lighting and powering equipment (32%); and natural and liquefied petroleum gas, which are used for heating and certain types of custom processing (13%) (Schnepf, 2004). In terms of energy costs, electricity dominates direct on-farm energy budgets (see Figure 2.2 for a breakdown of farm energy costs in the Northeast U.S.).

Figure 2.2. Northeast Farm Energy Costs in Production, 2003 ($ millions)(Adapted from Schnepf, 2004).



Specialty crops require especially high direct energy inputs, with costs for vegetable and melon crops amounting to $89/acre, as compared to $117/acre for fruit and nut trees, $310/acre for greenhouse and nursery products, and only $13/acre for oilseed and grain crops. On-farm energy use for specialty crops accounts for a much higher percentage of total value chain energy use than for other types of foods, with energy use on vegetable farms increasing 17.2 percent annually from 1997 to 2002 (Canning *et al.,* 2010). Despite involving less mechanized planting and harvesting techniques, fruits and vegetables require more involved and energy intensive handling, storage, and refrigeration post-harvest, and some of these activities take place on farms. Compared to conventional, larger-scale agriculture, soil-based urban farms are likely to use much less direct energy during the production phase, as manual energy largely supplants mechanical energy. Unlike large farms, few urban farms have dedicated onsite homes or habitable structures that require year-round temperature control and lighting–instead, most urban farmers live offsite.

For greenhouse production, the situation is quite different, and such structures in both urban and rural areas require considerable amounts of energy for climate control and lighting. CEA energy inputs are primarily in the form of electricity and natural gas. Depending on climate and season, electricity is chiefly used for lighting (especially in the winter months), and for cooling and ventilation in the summer, while natural gas used for heating in the winter. The competitiveness of such operations, especially those distributing locally or regionally, compared to field production, is heavily influenced by the relative price of petroleum versus natural gas and sources of electricity generation. Recently, petroleum prices have been high compared to historical averages, while the boom in natural gas exploration nationally has adjusted natural gas prices to their lowest in a decade (EIA, 2012). Geographic differences in energy prices are likely to have an effect as well. New York City, for example, has some of the highest electricity prices in the nation (EIA, 2011b), with the average commercial retail price for Consolidated Edison considerably higher than that of utilities in the peri-urban area (EIA, 2011c). See Table 2.1 for a comparison of regional electricity costs.

Table 2.1. 2010 Average Commercial Sector Retail Price, by Utility (from EIA, 2011c).

Utility	**Average Retail Price** (cents/kWh)
Consolidated Edison (NYC)	20.38
New York State Electric & Gas	10.21
National Grid	13.69
New Jersey Public Service Electric & Gas	13.86
Connecticut Light & Power	17.30
PECO Energy (Philadelphia)	12.81
NSTAR Electric and Gas (Boston)	16.39

This electricity price differential impacts the competitiveness of any commercial greenhouse operation located within NYC, and functions to incentivize energy efficiency measures or onsite generation in the city. Of particular interest are seasonal greenhouse management practices; specifically, whether operations continue year-round with large increases in energy costs during the winter months or production temporarily halts. Limiting the growing season poses marketing risks, as many retailers and wholesalers will be compelled to find alternate sources during those months. One interesting case study is the greenhouse at the Stone Barns Center for Food and Agriculture, which is not heated above 32°F throughout the winter. While this regime limits yields, the fact that the soil-based greenhouse (which allows for a geothermal heat effect in the soil) relies on cold-resistant varieties allows production to continue.

Many farms, particularly small-scale and urban farms, attempt to minimize not only direct inputs (which have direct impacts on the farms' balance sheets) but indirect inputs as well (which may have limited financial benefits or even negative financial impact for the farm but are linked to larger issues of environmental sustainability). In reality, most management and operations decisions made by farmers have impacts on both direct and indirect inputs. The installation of onsite renewable energy generation, selection of products made from recycled or renewable materials, and composting and other waste reduction efforts, are practices that affect a farm's bottom line but are often undertaken explicitly with the aim of reducing indirect energy impacts.

Processing food also requires large energy inputs. Between 1997 and 2002, the largest increases in food system energy consumption came from the processing sector (8.3 percent / year). Consumers and food service establishments increasingly turned to mechanized forms of processing and away from human labor in food preparation (due in part to convenience but also because of high labor costs). This growing reliance on technology accounts for about half of the total increase in energy use during that period, with energy use for processing of fresh vegetables increasing 11.7 percent annually (Canning *et al.,* 2010). Crops grown on farms in or near urban areas are less likely to be processed, for two related reasons: the direct or minimally-intermediated marketing channels favored by small-scale urban and peri-urban producers tends to put a premium on fresh produce, and close proximity to markets allows for delivery of fresh product with minimal need for refrigeration during transport. Whether the presence of urban agriculture actually decreases the amount of processed foods consumed in urban communities (and could therefore contribute to a decrease in total energy used for processing) or simply displaces fresh produce transported from greater distances is difficult to ascertain.

Food transportation also requires energy, primarily in the form of fuel for truck, rail, ship, or air transit, as well as refrigeration and maintenance en route. Transportation is a relatively small, albeit energy-intensive, contributor to total energy use for all foods. Freight-related services account for about ten percent of total energy use for fruits and vegetables, which is almost double the average of all other foods. Notably, in contrast to all other commodities, the food category encompassing fresh produce, oilseeds, and horticulture showed a decrease in average distance per shipment in the period from 1997 to 2007 (Canning *et al.,* 2010). This observation may be due to the fact that direct marketing and "local" food branding, while representing a minor component of the overall food market, are growing, particularly in the produce sector (Low and Vogel, 2011). This distribution component of the food system is often mentioned as an example of how more localized food systems could decrease energy use and therefore contribute to environmental sustainability. Energy use in transportation is a function of distance traveled and efficiency of transit mode, which complicates the picture, as certain long-distance modes of transportation, such as rail or ship, are more fuel efficient per pound of cargo than truck. Small truck transit from small farms distributing to farmers markets, for example, is a comparably inefficient form of transportation (see Table 2.2 for a comparison of energy used in different transportation modes).

Table 2.2. Fuel Use by Mode of Transportation (adapted from Albright and de Villiers, 2008).

Transportation Mode	Fuel Use (propulsion + maintenance) Btu / ton-mile
Rail	
Railcar	1,180
TOFC	1,380
Truck	
Refrigerated Intercity Truck, denser commodities (West of Continental Divide)	2,600
Refrigerated Intercity Truck, less dense commodities (West of Continental Divide)	2,900
Refrigerated Intercity Truck, denser commodities (East of Continental Divide)	2,400
Refrigerated Intercity Truck, less dense commodities (East of Continental Divide)	2,700
Local Refrigerated Delivery	3,300
Refrigerated Deep Draft Ocean Freight	480
Air Freight	27,000

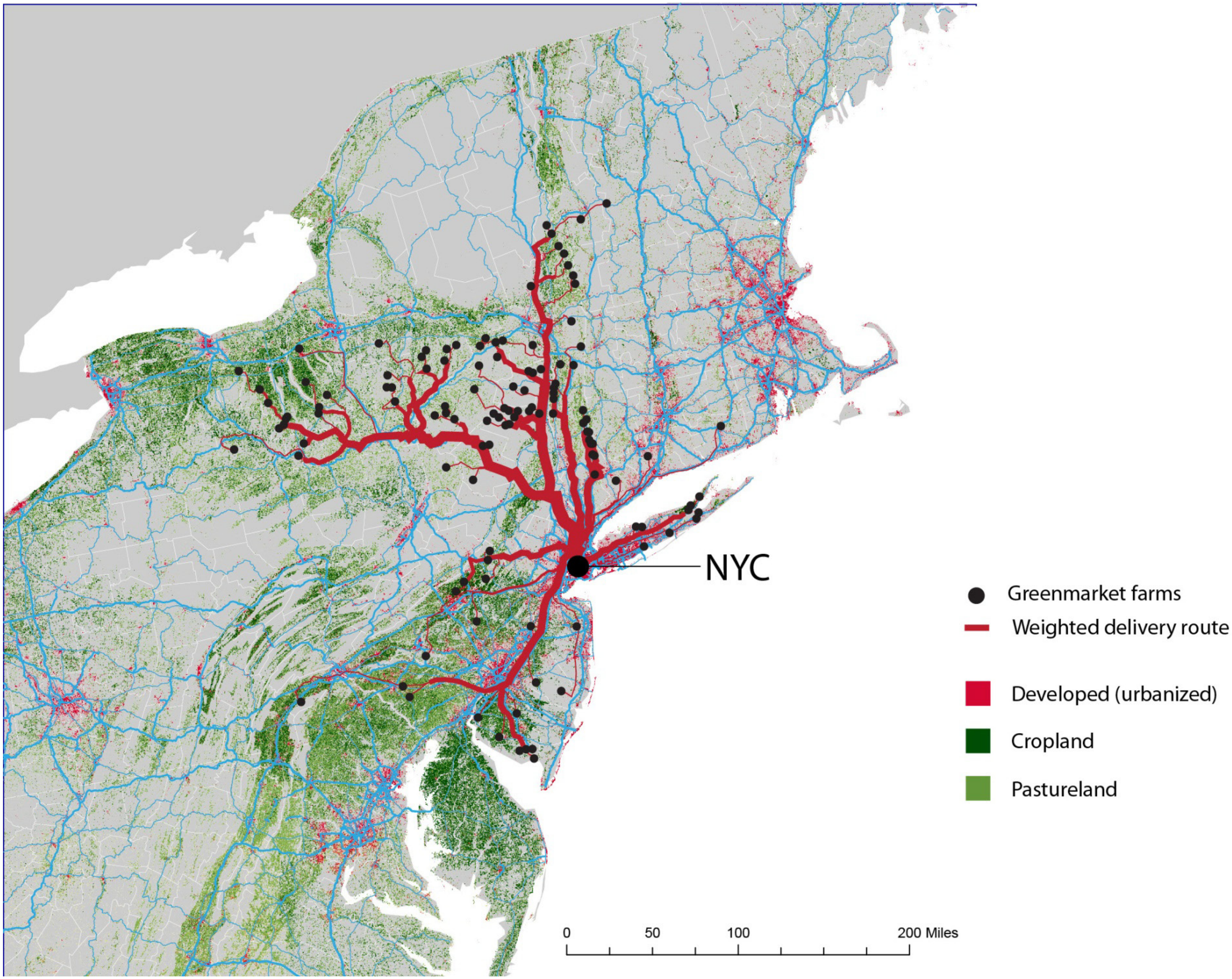
These differences may not be of a magnitude that would counterbalance the energy benefits of "local" (≤100 mile) distribution networks as compared to national food distribution averages (which, as noted in Section 1.5.2, are likely to be on the magnitude of 1,500 miles or more). It is important to consider that small-scale distribution, unlike continental rail transit, complicates the possibility of back-haul (other than compost, it is difficult to imagine what types of materials or commodities could consistently be transported from the city back to the farm). Small truck transit is less efficient not only in terms of energy use but also in labor requirements. This is a challenge for farmers participating in the GrowNYC farmers market program, which requires that farmers themselves be present to sell their products. For some farmers who drive from as far as 250 miles away (see Figure 2.3 for a map of farmers market farms and transit routes), this represents one to two days of lost labor, which can be an untenable prospect for some small-scale farms. The specific topography of the transit route is an important factor as well; products originating in California or elsewhere in the West must cross the Continental Divide to reach New York State (if traveling by ground transportation). This decreases the total efficiency of either rail or road transit, as even a slight grade can substantially increase fuel consumption (Albright and de Villiers, 2008). In any case, multiple forms of transit distribute most food products, and even a relatively efficient rail link often ends at a distribution warehouse from which trucks then transport the goods. In New York City, much of the available produce passes through the Hunts Point terminal wholesale market and from there small trucks transport the food to many of the city's small- to mid-scale grocery stores. Regardless of product origin or the mode of transport used to get to the city, all distribution systems must ultimately contend with a highly inefficient "last-mile" disaggregation strategy in transporting products to local retail, and products originating within or close to population centers are especially dependent on such small-scale networks. The large reduction in the overall distance between the farm and retailer or consumer that is enabled by urban agriculture, however, is likely to result in greatly reduced energy costs relative to more efficient long-distance transit modes. For example, produce originating at the Brooklyn Grange Navy Yard farm (the city's largest rooftop farm) would travel approximately 13 miles to the Hunts Point Terminal Market. From Hunts Point, it is ten miles via highway and local roads to the population centroid of NYC (posited here as a proxy for mean distance to retail), for a total of 23 miles driven by a local refrigerated delivery truck. Accounting for an approximate 20 percent reduction in fuel efficiency corresponding to driving conditions in urban areas (West et al., 1999) (the hypothetical route described is largely on highways, albeit with sections that are often highly congested), the total fuel use for this scenario would be just over 90,000 Btu/ton. For produce originating 90 miles from the center of NYC, which is the average distance of farms supplying the Greenmarket farmers markets, total fuel use for a small refrigerated truck driving to Hunts Point and on to the population centroid would be just over 300,000 Btu/ton (75 miles on highway, 15 miles in the city). For comparison, a distribution system employing a refrigerated intercity truck carrying denser commodities to Hunts Point and local refrigerated delivery to retail would require equivalent fuel consumption (c. 300,000 Btu/ton) if it originated 110 miles from the city. This is a 22 percent increase in distance, beyond which such systems reliant on intercity truck transit are less efficient (this analysis would have different results for rail or ocean freight distribution systems). In the case of some urban farms, such as East New York Farms, a majority of food sales takes place on-site, which eliminates transportation to retail entirely.

In addition to potential fuel savings, less time in transit leads to less spoilage and waste, which affects the total energy use per unit of food delivered to customers.

Retail uses energy for store operations including storage, refrigeration, lighting and climate control. There is no reason to suppose that scale or location of farming operation would necessarily have an effect on retail energy use, except to the extent that such operations are often associated either with farmers markets or other outdoor retail venues, which are less energy intensive, or with CSAs, which have no infrastructural retail presence at all.

Household level energy use, which is associated with transporting food from retailers to the home, and in food refrigeration, preparation, and cooking, represents the largest percentage of energy use in the food system, due primarily to the inefficiency of distributed car-based transit and small-scale cooking equipment and methods (Canning *et al.,* 2010). We see no reason why scale of food production and distribution systems should have any inherent impact on how food is prepared at home, except that fresh produce and fresh foods in general are likely to require more preparation and cooking energy than processed foods, for which preparation takes place in a more centralized manner (and therefore, presumably more efficiently). Similarly, consumers are not likely to use significantly different modes of transportation to access food from urban or peri-urban farms, although they may be going out of their way to buy such products, which could increase energy used in transit. In dense urban areas such as NYC, a vast majority of food purchasing trips takes place either on foot or by using public transit (NYC DEP, 2008). For these reasons, and because individual purchasing behaviors are generally outside the scope of this research, the systems boundary for evaluating energy use in differently scaled agriculture and food distribution systems need not include household energy expenditures.

Figure 2.3. Greenmarket Farms and Weighted Delivery Routes.



2.2. Methods for measuring the direct energy costs and benefits of the various techniques

While there has been little research specifically addressing the implications of systems scale on energy use, researchers have broader evaluations of food system energy use and have employed a variety of methods. Most prior research employs a spreadsheet model for comparative evaluations (for example Albright and de Villiers, 2008 and Pimentel, 1980), as do agricultural extension crop budgets and production reports, which for many crops are the most detailed sources of information.

The spreadsheet approach is a good model for understanding how agriculture and food distribution systems use energy, as well as a means of comparing different production methods for the same product types. However, it is generally used to evaluate single crop types, and therefore may not capture the energy implications of intercropping, polycultures, or other diversified production approaches that are typically employed by urban and small-scale specialty crop farmers. Ideally, one could construct a spreadsheet that includes investments, yields, and budgets for a diverse crop mix and compare these to the sum figures for the same mix of crops grown in conventional monocultures. An additional factor to consider with the spreadsheet approach is seasonal variability; growing seasons vary according to climate, with peak yields at the height of the season. Northeast suppliers focused on producing locally must either supplement with other sources or risk losing market share. The relative advantage of local production varies throughout the year and an ideal, but highly complex, spreadsheet model would capture this with separate seasonal or monthly budgets. Using the greenhouse operation at the Stone Barns Center as a case study, researchers at Cornell University are developing an integrated approach to evaluating production techniques, energy use, and marketing arrangements in a comprehensive database which aims to identify optimal seasonal crop mixes including such factors as land allocation, planting and harvesting dates, and labor requirements. This approach may yield very useful information about the long-term economic viability of small-scale production (at least of the greenhouse variety) in the Northeast and provide a replicable model for other such operations. Perhaps the greatest challenge with using a spreadsheet model is the difficulty of incorporating indirect energy inputs such as those associated with equipment and products used on the farm over multiple crop cycles or years. To do so would require assessing the average product life and distributing energy costs proportionally across its lifespan. A more useful approach would be to complete a similar study using a Monte Carlo approach with a variety of crops and environmental variables to explore the probabilistic issues that are inherent in this type of analysis. This could be done using any of a variety of programming languages, including Matlab or Java. Despite these limitations, the spreadsheet model may be more straightforward and flexible in terms of being able to accommodate these increasing levels of complexity.

Comparative energy analyses across different agricultural product types must evaluate the ratio between inputs (in this case, energy) and outputs that can be expressed as wholesale value, mass, volume, or some other measure such as calories. Fruits and vegetables (which consist mainly of water) tend to be high value and low calorie products (per unit of mass) as compared to grains, oils, or meat, which makes either measure not particularly useful. Caloric density may be an important factor when evaluating the capacity of a system to support a given population's basic survival. However, in the U.S., daily per capita calorie availability has been increasing steadily since the 1980's (USDA ERS, 2011), and the principal dietary challenge is caloric overabundance (and, in some cases, lack of certain other key nutrients found primarily in fresh produce). Caloric density is therefore a poor measure of foods' comparative importance in our food system, much less in our diets. Instead, for the purposes of this research, we propose an assessment of energy input per mass delivered to consumers, which is similar to the approach adopted by Albright and de Villiers (2008). This latter clause is critical because, while evaluations of agricultural systems usually focus on production yields (per area or per unit of input) establishing the system boundaries at the farm gate, in the case of urban and small-scale peri-urban agriculture the scale and methods of production and distribution are often inextricably linked. Many farmers who engage in urban agriculture do so with specific, small-scale alternative distribution and retail possibilities in mind, and perceive hyper-local distribution as both a marketing tool but also as a means of decreasing environmental impacts and contributing to food system awareness and community engagement. Direct energy per unit delivered to customer varies widely depending on key factors: yields per input (which will vary according to climate and management practices), transportation mode and distance, and shrinkage (food loss). Albright and de Villiers (2008) found that for selected produce, transport distance made a critical difference in local advantage (as far as energy use is concerned), while for others, climatic factors outweighed these benefits (disadvantaging greenhouse products grown in a cold winter climate). By measuring energy inputs per mass delivered to consumers, we can account for these factors as well as the potential effect of systems scale on food loss along the entire value chain. This is an increasingly important consideration, given that per capita generation of solid food waste increased 14.5 percent between 1990 and 2000 and an additional 10.1 percent between 2000 and 2007 (US EPA, 2008).

2.3 Methods for measuring the indirect costs and benefits of the various techniques, including economic, environmental, public health, and education

In this section, some of the additional implications of urban agriculture that may not be included in a spreadsheet model are examined. These include energy benefits attributable to urban agriculture that may accrue by the surrounding buildings or neighborhood (specifically those relating to rooftop agriculture), as well as potential economic, health, and educational benefits.

2.3.1 Energy Implications

Many forms of urban agriculture have the potential to function as green infrastructure, providing ecosystem services such as stormwater remediation, habitat diversity, and some of the recreational and psychological benefits of green space in urban areas. Additionally, increasing green space can have indirect impacts on the energy consumption of buildings and surrounding neighborhoods. Green space mitigates the urban heat island (UHI) effect, and agricultural green roofs can decrease building energy use if properly installed and managed. In this section, we discuss methods for assessing these effects.

Green roofs, which include open-air rooftop farms, are layered systems consisting of a waterproofing membrane, growing medium, and the vegetation layer itself, which often also includes a root barrier layer, drainage layer, and an irrigation system (Castleton *et al.,* 2010). The energy fluxes in this system involve shortwave and longwave radiation both downward (into the building) and upward (into the atmosphere), and conductive, convective and latent heat flow, as shown in the following energy balance equation:

$$Shortwave_{down} - Shortwave_{up} + Longwave_{down} - Longwave_{up} - Q_{convection} - Q_{conduction} - Q_{latent} = 0$$

(Gaffin *et al.,* 2006). A green roof can provide many benefits to a building and its surrounding environment, including energy savings deriving from the process described above, stormwater management, improved water runoff quality, improved urban air quality, extension of roof life, and a reduction of UHI. There are two main types of green roofs, with differing influences on the building and environment. Extensive green roofs are oriented towards environmental performance, have a lower profile (and weight), and often use plants of the sedum genus as a hardy, low-maintenance cover. Intensive green roofs are designed to support flowers, trees, shrubs, and/or crops, and thus serve as an accessible outdoor space and amenity.

Rooftops (of which 11% are flat roofs), account for 19% of New York City's surface area and a substantial portion of available open space (Solecki *et al.,* 2006). Rooftops constitute roughly 40 percent of all impervious surface of NYC's developed area (Hutchinson *et al.,* 2003). Due to their generally large footprint, limited height, and superior structural capacity, older industrial buildings are often more suitable than residential and commercial buildings for green roof retrofit in NYC. Additionally, older buildings derive the greatest benefits from the additional green roof layer, because they are often poorly insulated unlike newer structures. Green roofs are still a relatively new form of ecological infrastructure in North America; however, NYC has the potential to be a trendsetter in the rooftop farm arena.

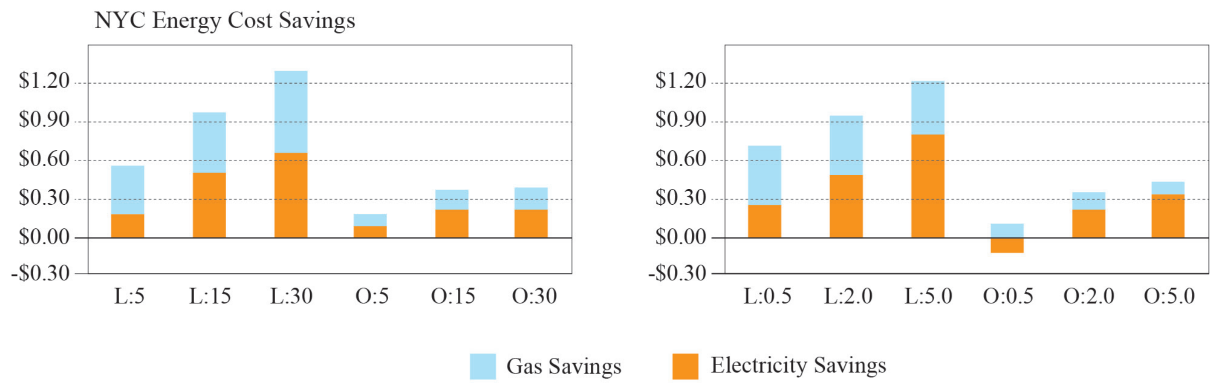
Greenhouses employing sophisticated climate and nutrient controls systems, or CEA, are another option for rooftop food production. Due to structural limitations, rooftop greenhouses usually involve hydroponic growing, which involves much less mass than soil-based systems. CEA is a combination of engineering, plant science, and automated greenhouse control technologies used to optimize plant growing systems, plant quality, and production efficiency. Some of these greenhouses can be integrated into the host building's climate control systems in an approach called Building-Integrated Agriculture, which can involve horizontal rooftop greenhouses and those vertically integrated in double-skin facades. A combined building and rooftop greenhouse structure can bring energy benefits by: reducing heat losses and gains through the building roof, using waste heat from the building to heat the greenhouse, using excess solar gains in the greenhouse to heat the building (on cold but sunny days), and low-energy evaporative cooling methods to cool the building as well as the greenhouse (Delor, 2011). The following sections provide an overview of the literature on the potential benefits of green roofs in terms of building energy consumption and urban heat island effect, and the potential for building-integrated greenhouses.

2.3.1.1 Energy implications of rooftop farming

Theoretical modeling, experimentation, and simulation are three main methodological approaches to evaluating a green roof's impact on the energy efficiency of the host building. These approaches can also be applied to rooftop farms. Theoretically, green roofs impact the building thermal environment and energy use through four processes: 1) long-wave and short-wave radiative exchange within the plant canopy; 2) plant canopy effects on convective heat transfer; 3) evapotranspiration from the soil and plants; and 4) heat conduction (and storage) in the soil layer (Sailor, 2008). Sailor accounted for such mechanisms and established a green roof energy balance model, which combines a soil and plant canopy energy balance model, and a moisture balance model, incorporating the energy budgets for the foliage layer and for the ground surface. Prior to the development of this comprehensive model, other theoretical models incorporated various essential factors that influence the energy benefit of buildings. Del Barrio's mathematical simplified dynamic green roof model (1998) found that heat flux entering into the building through the roof decreases as thickness of the soil layer increases, the soil moisture content increases, or soil density decreases due to diminishing thermal conductivity. Considering also that LAI (an indicator of vegetative cover) determines the role of plant canopy as a shadowing device, the author concluded that a well-designed and managed green roof could behave as a high quality insulation device in summer, although a green roof could not act as cooling device itself. Emorfopoulou and Aravantinos (1998) incorporated the distinction between buildings with and without existing thermal insulation in their stationary mathematical model to calculate the predicted temperature below each material layer for a bare roof and green roof. Based on their analysis, on a planted roof with thermal insulation, the temperature differences between the interior and exterior area would not exceed 2.5°C. In contrast, on a planted roof without thermal insulation the temperature differences were 5°C, in which case the choice of the material in the drainage layer would be more important. They concluded that the planted roof contributes to the thermal protection of a building, but does not replace the thermal insulation layer. Rosenzweig *et al.*(2006) theoretically modeled energy balance in quasi-equilibrium in a spreadsheet and found that a high albedo (solar reflectivity) of 0.7~0.85 was required on a white roof to reproduce the surface temperatures observed on the green roofs. Feng *et al.* (2010) used a mathematical and experimental model to find that of the dissipated heat from a green roof, 58 percent was lost by evapo-transpiration and net photosynthesis effects accounted for 9.5 percent of the dissipated heat. Direct measurement of roof temperature and heat flux via experiment can serve either as a stand-alone approach or be used as an input collection or calibration tool for theoretical or simulation models. Measuring air temperature at various heights above a green roof and throughout the structure using thermocouples, researchers found that the ambient air temperature above the vegetation was reduced significantly after sunset (Wong *et al.,* 2003), and the building's internal temperature was lowered and its peak was delayed (Liu and Minor, 2005). Wong *et al.* (2003) used the measured temperature data to calculate the thermal resistance (equivalent R-value) of different soil moisture conditions and plant types (turf, shrubs, trees) using a simple steady-state equation and integrated it into the DOE-2 energy simulation program. Contradicting Del Barrio's theoretical results, they demonstrated that wetter soil was a poor insulator, leading to higher sensible cooling loads compared with dry soil (due to the higher value of thermal resistance of dry soil). Shrubs were the most effective plant type for reducing building energy consumption, due to their high LAI value. Researchers also calculated building cooling and heating energy consumption using standard air-conditioning efficiency based on heat flux loss under different roof treatments measured by installing a below-insulation-board thermistor under the green roof (Gaffin *et al.,* 2010). The green roof was found to provide insulation equivalent to R-100 (US units) while the white roof could provide insulation equivalent to R-50 during the warm months of the year for NYC. Furthermore, it was suggested that green roof performance would improve over time due to plant growth, while the white roof temperature benefits would degrade due to loss of reflectivity.

Several existing simulation packages with varying features can be used for computational modeling of a green roof. The Transient System Simulation Program (TRNSYS) has the capability to numerically model all evapotranspiration and metabolism process of plants. As an example, it has been used to calculate the annual energy requirements for an office building in Athens with different roof insulation values, whose simulation results were validated against the collected green roof measurements (Niachou *et al.,* 2001). The thermal simulation package Environmental Systems Performance-research (ESP-r) uses the finite element approach to model heat, air, moisture and electrical power flows, and as a simulation example, it was adopted to model a multi-story residential building in Madrid, Spain (Alcazar and Bass, 2005). Specifically, the researchers in that study found that soil moisture could increase the green roof U-values because water is a better conductor than air, consistent with the above Wong *et al.*'s study. Sailor (2011) carried out his theoretical model as an "ecoroof" module in the building energy simulation engine EnergyPlus, in which users can specify growing media depth, thermal properties, plant canopy density, plant height, stomatal conductance, and soil moisture conditions, among other parameters for the input object "Material: RoofVegetation," together with irrigation schedule. Such input values can be either defined by accepting default values in EnergyPlus (Scherba *et al.,* 2011), or further fine-tuned through parametric sensitivity analysis (Grant, 2007). The ecoroof model was applied to compare green roof energy saving effects with those of conventional roofs and highly reflective white roofs (Sailor *et al.,* 2011). Figure 2.4 shows the energy cost savings in terms of natural gas and electricity of green roofs in NYC. It was found that green roofs of all three soil depths (5, 15, and 30 cm) and all three values for LAI (0.5, 2.0, and 5.0) could save energy year-round compared to conventional roofs for both residential and office buildings. With an increase in LAI, the energy savings for a green roof increase in summer but decrease in winter compared to a conventional roof. On average, a NYC residential building would decrease gas energy use by 48,000 kJ/m^2 annually with the baseline green roof (soil depth=15cm, LAI=2). When compared to a highly reflective white roof, however, only the green roof with high LAI saves more year-round energy for multi-family lodgings, whereas the baseline green roof is less efficient. Specifically, the high LAI green roof showed a gas savings and electricity penalty in comparison to the white roof though the electricity penalty was lower than for the baseline green roof. This is because the primary advantage of a white roof over a green roof is the decreased solar gain through the roof, and the high LAI green roof absorbs the least amount of solar energy.

Figure 2.4. Annual energy cost savings per square meter of roof for green roofs on lodging (L) and office (O) buildings with three soil depths (5, 15, and 30 cm, left), and three LAI values (0.5, 2.0, and 5.0, right), compared to a conventional roof (adapted from Sailor *et al.,* 2011).



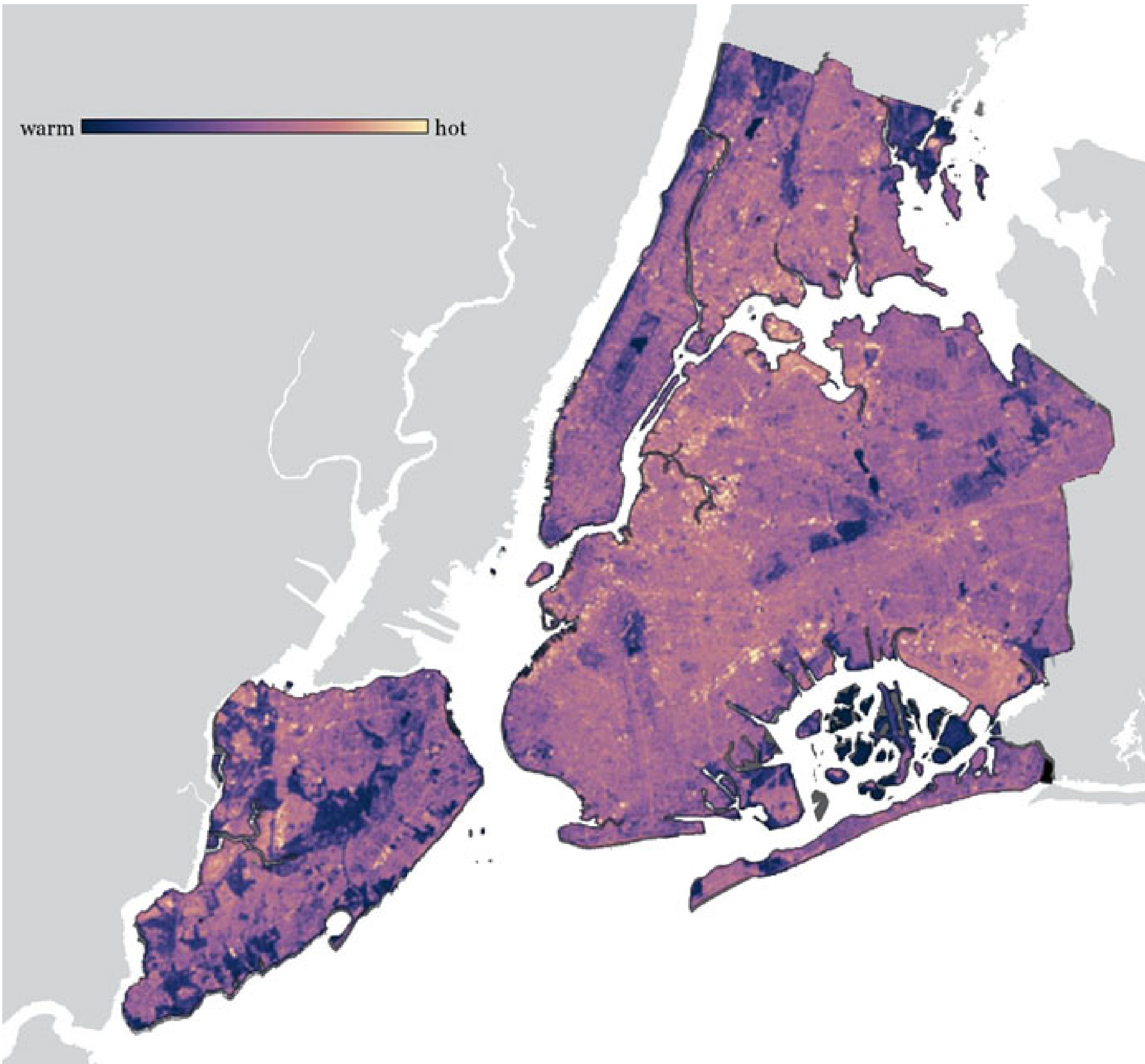
In sum, LAI, soil depth, irrigation, and existing roof insulation are the four most influential factors in determining the energy impact of a green roof on the host building. Critically, a rooftop farm differs substantially from a standard green roof as far as these factors as concerned. Among the available methodologies, we recommend Sailor's ecoroof model (2008) as the best suited to evaluate these variables. Generally, a green roof with a high LAI is expected to contribute greater building energy benefits. The most likely vegetable types to be planted on a rooftop farm are highly variable as far as LAI is concerned, they are likely to be akin to standard field crops such as grains or soybeans, grasslands, or shrublands (which have LAI of 3.6, 1.7, and 2.1, respectively). Sedum species are most like plants found in tundra environments (which have an LAI of 1.9) (LAI figures derived from Asner *et al.,* 2003). Another important consideration is that vegetables' LAI will vary with the seasons, while sedum remains relatively constant; indeed, sedum species are selected specifically for their hardiness to winter conditions. The greater cover canopy of vegetables in summer could lead to greater energy benefits for the host building during the summer, while not impeding solar gains into the building from the roof when the crops are dormant in the winter. Therefore, vegetables grown in rooftop farms could have larger energy saving potential compared to sedum. As mentioned, actual LAI values vary considerably from crop to crop (consider, for example, the leaf area differences between carrots and squash). Destructive harvesting and calculation of single-sided leaf area weighing of paper replicates, or an optically based automatic area measurement system can determine LAI. Average LAI values for the entire roof must be determined, as rooftop farms often incorporate unvegetated paths, equipment areas, and access points which could counteract the potentially higher LAI values for the planted areas. As for the second key factor, thicker, less dense growing media characteristic of standard green roofs may offer better insulation to the building below; however, the actual impact of soil moisture content (and therefore of the more intensive irrigation regimen necessary for farming) is still uncertain. As noted above, the conductivity of the soil medium increases with moisture content, meaning that dryer soil conditions offer better thermal insulation, as verified by Wong *et al.*'s experiment and simulation study. On the other hand, other studies have shown that wet soil provides thermal resistance due to its latent thermal capacity (Minke and Witter, 1982). Water through evaporation from plant surfaces and soil can remove latent heat energy absorbed by plants. The aggregate effect of these opposing mechanisms is still in question, although higher irrigation rates resulted in electricity savings in summer as calculated by some simulation packages, e.g., EnergyPlus (Sailor, 2008). The soil media attributes for rooftop agriculture can be determined by simple observation of soil and control of the irrigation schedule, and representative values for green roof growing media can also be found in Sailor *et al.*'s study (2011). Lastly, to incorporate the influence of existing insulation on a green roof's energy benefits, it is necessary to determine the building codes in place during the year of construction to deduce the U-value of a building as a model input, as each U-value range has corresponding energy saving potential from the adoption of a green roof (Castleton *et al.,* 2010). The fact that the older industrial buildings (built between 1900 and 1970), on which green roofs are often installed in NYC, are generally poorly insulated magnifies the energy saving potential of a green roof, which could therefore exceed the predicted outcomes of the aforementioned studies (Sailor *et al.,* 2011).

2.3.1.2 Urban Heat Island effect

Beyond the energy saving impact on individual buildings, urban agriculture, as a form of green space, can help mitigate the UHI effect by reducing average surface temperatures at a neighborhood or even city scale (see Figure 2.5 for a map of areas most affected by elevated summertime temperatures). There are several possible approaches to modeling the impacts of this phenomenon. Solecki *et al.* (2006) designed a method to test the impact of 10 and 50 percent green roof infrastructure adoption scenarios on average NYC surface temperatures. Thermal satellite imagery was used to characterize surface temperatures associated with particular land-use classes using GIS. The average surface temperature of the "grassland" class was then used as a proxy for the surface temperature associated with a green roof, and the initial temperature of the specified available rooftop area was replaced with this value. Average surface temperature was calculated as an area-weighted value: $\sum(A_i \cdot T_i)/A_{total}$. The researchers found a temperature decrease of ≤1.4˚F for the 50 percent green roof replacement scenario under optimal modeling conditions, in which high resolution satellite data was available and high temperature rooftop surfaces were differentiated from the generally cooler ground-level surface.

Using another approach (Rosenzweig *et al.,* 2006), satellite-derived surface temperatures were regressed on other satellite-derived and/or GIS-based environmental variables to determine the extent to which surface temperature depends on vegetation, albedo, and other land-surface characteristics. The Penn State/NCAR Mesoscale Model (MM5), which has the capability to dynamically simulate the interactions among a range of land-surface cover and climate variables (Grell *et al.,* 1994), was then used to determine potential reductions in surface temperature and near-surface air temperature for nine mitigation scenarios. Average temperature reduction over all times of day by green roofs in this simulation was found to be 0.4°F throughout NYC, or 1.1°F for the mid-Manhattan west neighborhood. Compared with other mitigation scenarios, green roofs offer greater cooling per unit area than light surfaces such as white roofs, but less cooling per unit area than curbside planting, and therefore may be the best option in neighborhoods with limited street-level redevelopment opportunities.

Figure 2.5. Temperature Differential in NYC on 8/14/02 at 10:30 a.m. (Landsat imagery from Gaffin and Simon, 2005).



Considering that the second approach requires expertise in simulation using MM5 and its suitability in studying localized changes, the first approach requires relatively fewer inputs to conduct a citywide study. The necessary datasets in the first approach (i.e., land surface temperature and land cover) are widely accessible resources, and this method can therefore be replicable in many urban areas for UHI studies. This is a potentially effective methodology for evaluating the macro-scale temperature effects of wider adoption of green roofs or green spaces; however, we suggest that the results may be more accurate if average temperatures for the "urban open space" land use category are substituted for the targeted areas as opposed to "grasslands". The former classification, encompassing everything from parks to gardens to golf courses, may be more representative of the varieties of crops and land cover found in urban agriculture. Given that surface temperatures are elevated in urban open spaces when surrounded by asphalt or other heat absorptive, impermeable materials, the anticipated UHI mitigation effect may be smaller using this modeling approach.

The primary benefit of UHI mitigation is energy conservation due to a corresponding decrease in air-conditioning usage. Assuming that air-conditioning is turned on when temperature rises above 65°F in summer, and that the average daytime summer temperature in NYC is 80°F, researchers found that this 15°F gap used in heating-degree-day calculations could be reduced by approximately five percent by adopting green roofs using Solecki's model mentioned above. This would result in a five percent reduction in energy demand for cooling, or equivalently total cost savings of $213 million for NYC (Acks, 2006). In addition to reduced energy demand, mitigation of NYC's heat island could improve air quality and public health, increase property values, as well as reduce the city's contributions to greenhouse gas emissions (Rosenzweig *et al.,* 2006).

2.3.1.3 Energy implications of building-integrated Controlled Environment Agriculture

Delor (2011b) uses simple spreadsheet calculations to quantify the energy benefit of building-integrated CEA and found that the combined structure could save up to 41 percent in heating load, compared to conventional stand-alone greenhouses and buildings. Caplow and Nelkin (2007) also developed a spreadsheet model and found that a rooftop greenhouse could serve as a complete HVAC system utilizing evaporative cooling. The required inputs, which include 550 tons of water and 23 MWh per year of power for fans for the building-greenhouse combined system, are lower than the energy cost to cool the building alone using conventional air-conditioning. Other than these two highly simplified spreadsheets, rigorous research on quantifying the energy savings from building-integrated greenhouse is still lacking. In the future, studies that are more comprehensive should take into account the convective dynamics and thermal storage of the integrated system as well as nuanced temperature and insolation profiles. Pending more in-depth research, the consensus seems to be that the energy impacts of a rooftop greenhouse are similar to that of a green roof, but are especially beneficial to poorly insulated buildings. Conversely, the cost of constructing a rooftop greenhouse is approximately three times that of installing a green roof, though if properly designed and managed, annual yields may be of an order of magnitude higher than for an outdoor rooftop farm (Delor, 2011).

Although the energy benefits of building-integrated greenhouses have not been adequately assessed, existing projects have widely adopted external renewable technologies such as solar panels and rainwater capture to save both energy and water, while also mitigating stormwater overflow. One example is Gotham Greens in Brooklyn, the nation's first rooftop commercial hydroponic greenhouse in an urban setting. It aims to make its operation nearly carbon neutral, utilizing numerous technologies to mitigate traditional greenhouse energy use burdens. Consequently, Gotham Greens may produce vegetables with a lower total energy input per kg of delivered product than either conventional CEA or conventional field agriculture. The electrical needs of this urban CEA facility are met in part by on-site solar photovoltaics, and its re-circulating hydroponic methods use ten times less land and 20 times less water compared to conventional agriculture (Puri, 2011). As another case study for future research, the world's largest rooftop farm is to be constructed by BrightFarms on Liberty View Industrial Plaza, an eight-story 1.1 million-square-foot warehouse building in Sunset Park, Brooklyn. This rooftop hydroponic farm is being designed to grow enough produce to meet the fresh vegetable consumption needs of up to 5,000 New Yorkers and to prevent 1.8 million gallons of stormwater from going into local waterways. Another example of this model at work is the Sun Works Center at the Manhattan School for Children, a rooftop greenhouse with water tanks that can capture up to 40,000 gallons of rainwater a year.

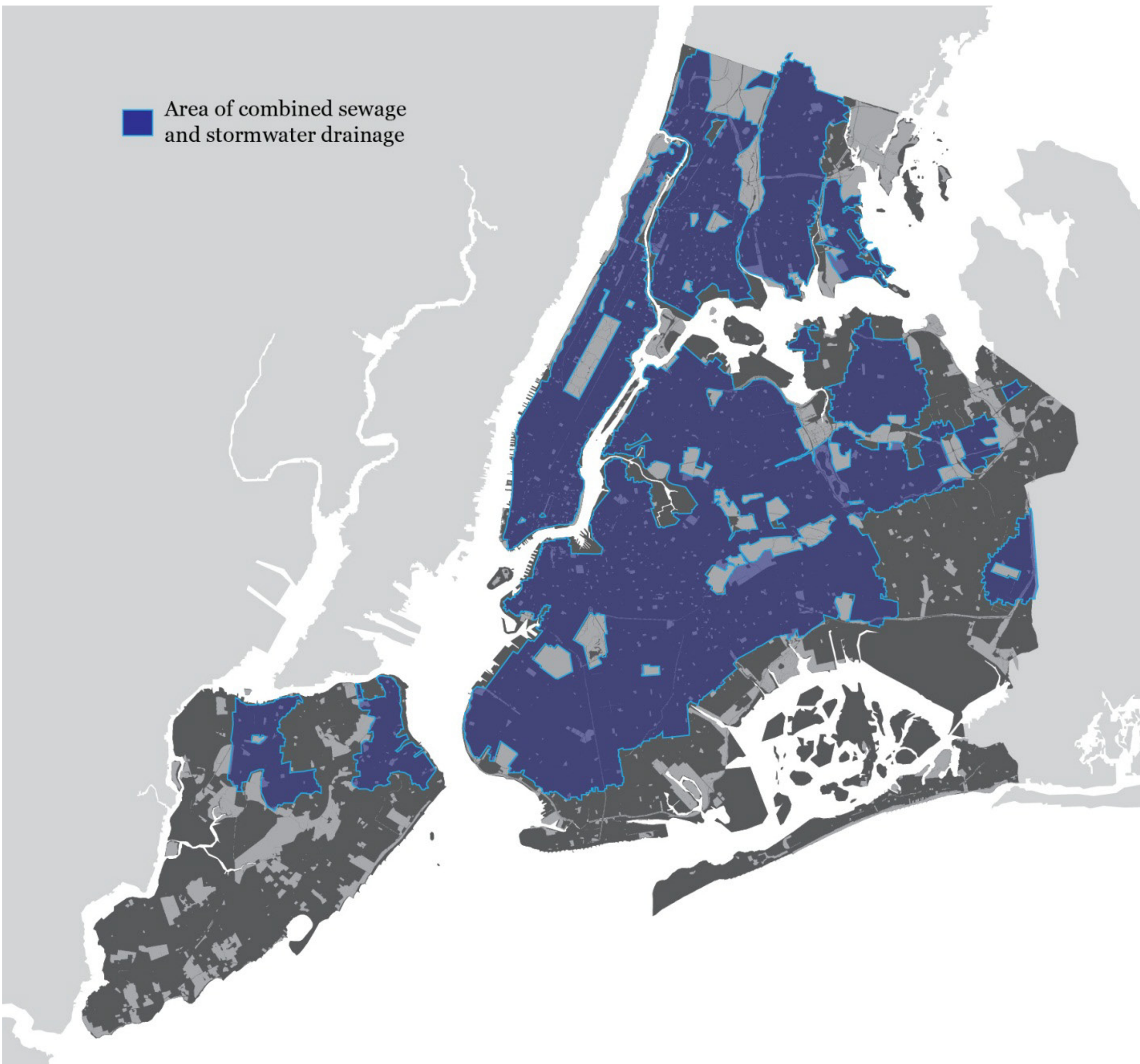
While there are no extant full-scale examples of vertically integrated growing systems, the 2020 Tower, designed by Kiss+Cathcart Architects (2010) is an interesting conceptual model, consisting of a mixed-use, zero net-energy building with vertical farming introduced into the façade. The skin of the building is a multilayer system consisting of photovoltaics, rainwater capture, biological screens, and integrated food production, which could accommodate vines or hydroponic growing systems. Such vegetation could provide seasonal shading, evaporative cooling, thermal mass, air filtration and oxygenation, as well as psychological benefits.

2.3.2 Stormwater Remediation

Urban agriculture has the potential to impact water use and stormwater runoff, in addition to its energy impacts. The problem of stormwater runoff and CSO into the city's waterways is one of NYC's most intractable environmental challenges. Given the prohibitive expense of establishing increased treatment capacity through "gray infrastructure," or large-scale, centralized approaches, the DEP is proposing the complementary, decentralized "green infrastructure" approaches of rainwater capture and increasing permeable surface area. Urban agriculture could provide both of these services: through rooftop rainwater harvesting, which is already being practiced at many community gardens, and by increasing urban green space and thus water detention and retention. These approaches are outlined in the PlaNYC Sustainable Stormwater Management Plan from 2008, and more recently in the NYC Green Infrastructure Plan released in 2010, which will be supported by $1.5 billion in investments over the next 20 years (NYC DEP, 2010). The Green Infrastructure Plan calls for a reduction in CSO volumes by an additional 3.8 billion gallons per year, which will be primarily achieved through green infrastructure approaches, including capturing rainfall from ten percent of the impervious surfaces in the Combined Sewage Watersheds (CSWs). (Figure 2.6 is a map of areas in NYC that have combined sewer and stormwater systems). This would be achieved in part by adding anywhere from 993 acres (assuming 25% of acreage required for the 10% capture goal would consist of planted areas) to 2,978 acres (75% of acreage would consist of planted areas) of fully vegetated area to the CSWs (NYC DEP, 2010). According to our assessments, there are 477 acres of public vacant land and 1,472 acres of private vacant land in the

CSWs. The DEP estimates that 78 percent of the city's land consists of impervious surfaces; within the CSWs, which exclude much of Staten Island (which has the highest ratio of green space of any borough), that figure is likely to be higher. Vacant land consists of 60 percent impervious area on average; converting all of this vacant land in the CSWs to urban farms or other fully vegetated areas would increase total permeable area by 1,169 acres. Capturing rainwater from 3,700 acres of rooftop area in the CSWs would add an additional five percent to meet the city's goal.

Figure 2.6. Combined Sewer Outfall areas in NYC.



The impacts of agricultural green roofs on stormwater runoff mitigation can vary. Green roofs can reduce CSO events in two ways. Detention occurs as soil absorbs rainwater and eventually releases once reaching a saturation point. The delay between a period of heavy rainfall and the eventual release of the water into the sewer system has the benefit of decreasing the overload on the treatment systems, which result in CSOs. Retention occurs as soil absorbs rainwater and then eventually evaporates directly from the soil or through the process of evapotranspiration in plants. Retained water never makes its way into the sewage system. As far as detention is concerned, rooftop farms could have an advantage over conventional green roofs in that deeper growing medium is required: at least six inches, and often up to ten inches of soil or other medium, as opposed to two to four inches for sedum plantings. Deeper soils generally detain more water; however, this benefit could be partially offset by the fact that food crops generally need to be irrigated, and soil that is partially saturated is less effective at absorbing additional stormwater. Detention rates vary widely depending on the type of growing medium used, although there are indications that soils which are replenished through composting have increased hydraulic conductivity (City of New York, 2010). Another factor is the degree of pre-saturation, which is determined by time between rainfall events and how much irrigation is used. Farmers (at least of the outdoor variety) are well attuned by necessity to the weather forecast and will make decisions on when to irrigate accordingly. It is difficult; however, to account for the vagaries of behavior and varying crop needs when estimating the stormwater mitigation potential of agricultural green roofs. As for retention, the differences between agricultural and conventional green roofs are equally complex. Again, deeper soil is assumed to have greater retention capacity. There is some indication there is an optimal soil depth beyond which retention decreases (NYC DEP, 2010). This observation is possibly because solar energy penetration decreases with depth and deeper soils dry more slowly than shallow ones. (This research was performed on roofs planted with shallow-root sedum, and it is possible that deeper root crops could offset this factor with increased water transpiration from the bottom of the soil layer). The greater surface area of food crops compared to sedums could also increase evapotranspiration rates, at least during the growing season, while during the winter months conventional green roofs would likely perform better.

Given that the "existing development" land use category is by far the largest in the CSWs, it seems that focusing interventions on existing buildings would represent the greatest potential for mitigating stormwater runoff in these areas. The NYC Green Infrastructure Plan prioritizes the creation of green roofs primarily for new development and multi-family residential complexes, while concluding that they are not cost effective as compared to other approaches to mitigating runoff for most other existing development. This finding has been challenged by researchers who claim that the maintenance cost estimates used in the city's evaluations are inaccurate, and the savings incurred from the greater longevity of green roofs were not factored into the analysis. Researchers at Columbia University have measured a retention rate 22 times higher than that assumed in the PlaNYC analysis, which would change the cost-effectiveness ranking of green roofs from the least cost-effective to the most cost-effective of considered measures for stormwater retention (Gaffin *et al.,* 2011). Furthermore, areas with the highest concentration of buildings that could be suitable for rooftop agriculture, such as around the Newtown Creek, Gowanus Canal, and in the Hunts Point neighborhood in the Bronx, are also areas which have high rates of surface runoff for the same reasons (namely, large rooftop areas and few green spaces).

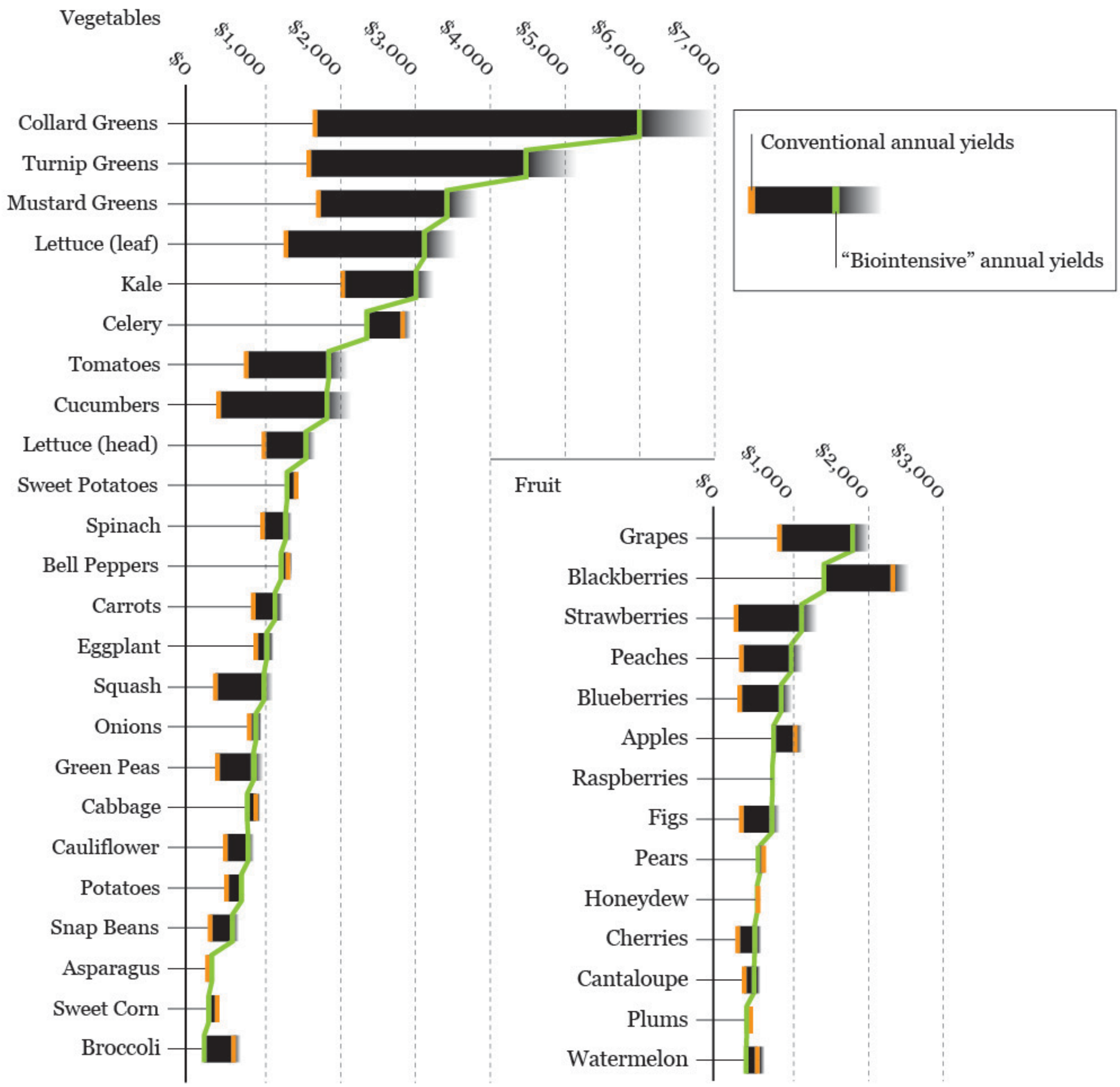
Another point to consider is that decreasing stormwater runoff from rooftops has benefits beyond reducing CSO incidence. Contaminants from roofscapes and streetscapes can make their way into the city's waterways regardless of CSO events, either because sewage treatment plants are not designed to treat such pollutants or because of direct runoff into waterways. There are indications that conventional green roofs can reduce pollutant runoff in water through filtration and biological uptake of nutrients (Köhler and Schmidt, 2003); however, green roofs have the potential to leach contaminants into runoff as well. Intensive composting operations, whether on rooftops or at ground level, have the potential to leach nitrogen into waterways if runoff is not well managed. For this reason it is important that more research take place on the composition and potential contaminants from various rooftop growing media, and that growing methods in urban areas conform to organic or more stringent standards. It is important to note that green roofs alone will not solve the CSO issue – a study of the Gowanus Canal Watershed estimated that covering 100 percent of suitable buildings in that area with green roofs would result in a 26 percent reduction in CSO volume (Montalto *et al.,* 2007) – but rather part of a larger set of strategies. Clearly, much more research is needed to understand the degree to which agricultural green roofs can reduce runoff, as research to date has focused on conventional green roofs.

Other than increasing the amount of permeable surface area in NYC, urban agriculture contributes to stormwater mitigation with direct source-controls, such as rooftop rainwater harvesting or "blue roofs," which also decreases water use if used for irrigation. Such systems are potentially more cost effective than green roofs from the perspective of mitigating runoff (installing a 55 gallon tank results in an annual cost of $0.18 per gallon captured while a green roof has an annual cost of $3.33 per gallon captured (City of New York, 2010). There are favorable conditions in NYC for rooftop stormwater harvesting because of its density (most available lots for farming are surrounded by existing structures) and because of its relatively wet climate. In this climate, farmers and gardeners can generally plan for five to six gallons of storage capacity per square foot of roof area. One of the challenges to installing such systems is obtaining the consent of the owners of the buildings adjacent to farms or gardens although, in some cases, there are clear benefits to the building. Catchment systems can divert water away from building foundations and mitigate basement flooding and mold and mildew in basements and walls. There are already a number of rainwater collection systems operating in farms and community gardens in NYC, with 62 installed by GreenThumb since 2002. Gardeners have found that during most summers the systems can supply most or all of the water necessary to irrigate the garden, though unusually hot and dry summers require additional water sources. GreenThumb has estimated that each year, these 62 systems divert an average of 772,156 gallons of rainwater from the city's sewer systems, with a total cistern capacity of 39,849 gallons collected from a catchment area of 45,468 ft^2 (Personal communication with Lenny Librizzi, Assistant Director, Open Space Greening, GrowNYC).

2.3.3 Economic Benefits of Urban Agriculture

Urban and peri-urban small-scale agriculture also has an economic dimension that is important to consider, and its potential as a tool for economic development is often overlooked. It is true that urban agriculture represents a small part of the overall agricultural economy, and while small-scale peri-urban farming is becoming more prevalent, this sector still represents only a small percentage of overall food supply. As discussed in Section 1, however, such operations often generate more economic value which is disproportional to their size. The value is partially due to more intensive cultivation techniques, but also due to the price premiums associated with direct or minimally intermediated marketing arrangements (See Section 2.4 for a more in-depth discussion of economic challenges). Recent research, for example, found that farmers who participate in local food sales, whether through direct or intermediated marketing, grew high-value commodities that averaged $590 per acre vs. $304 per acre for the average farm in the U.S. (Low and Vogel, 2011). Figure 2.7 shows potential values for a number of fruit and vegetable crops grown on a 1,000 ft2 plot using data from the USDA sources for conventional yields and Jeavons (2006) for biointensive yields (see description of methodology for Table 1.2 in Section 1.6). These were then multiplied by average organic retail prices (derived from Hyman and Stewart, 2011, and Buzby et al., 2011), which includes data on organic premiums for select products. Organic price estimates were used with the assumption that most crops grown in urban areas will be marketed at a price range that is closer to organic than conventional prices due primarily to the price premium often associated with small-scale, sustainable production methods. The figures reflect average U.S. prices; there is evidence to suggest that food prices in NYC are equivalent to, or in some cases lower than, other parts of the country (Handbury and Weinstein, 2011). Producers in urban areas have the additional advantage of having a large consumer base nearby which facilitates direct marketing. Additionally, it may be that the higher land values associated with urban areas selectively favor operations with higher profits, as those who do not have successful marketing arrangements are not likely to survive for long.

Figure 2.7. Potential Annual Crop Value, 1,000 ft^2 bed.



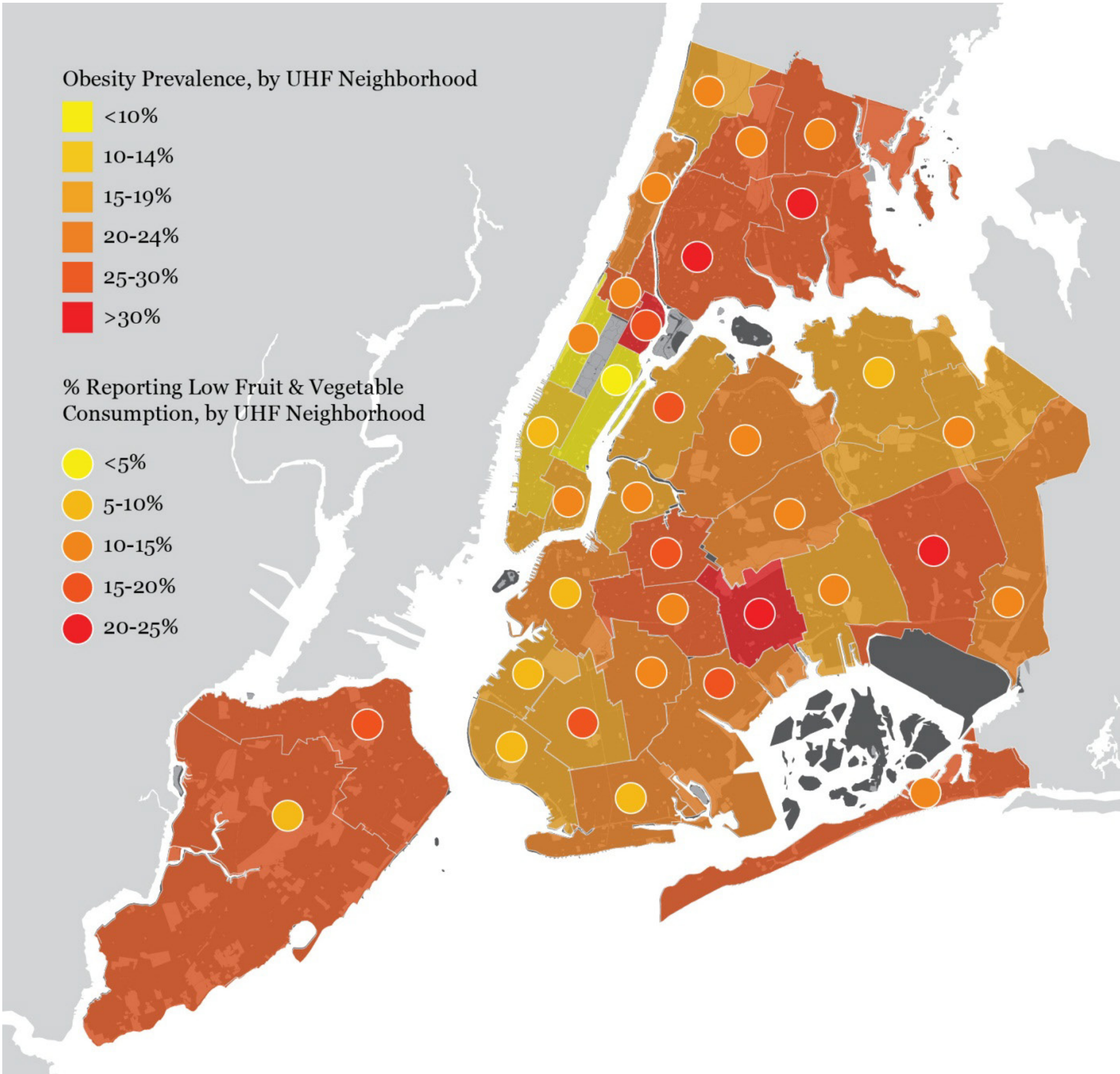
One of the challenges of advocating for agricultural activity in cities is that it is unlikely to be competitive if evaluated against many other types of economic activity, if either profits or employment is used as a measure. Policymakers, who are under continued pressure to demonstrate the economic benefits of any initiative they advocate, may be reluctant to support urban agriculture given the average urban farm may provide three or fewer full-time jobs and annual sales in the tens or hundreds of thousands of dollars, if a different form of commercial or industrial business is vying for an available site. In a city such as NYC, where despite the economic downturn housing prices are still high and there is the added impetus for more housing (whether for low-income applicants or higher-priced condominium development), urban agriculture is unlikely to occupy a large footprint in the most densely developed neighborhoods. If, however, we consider urban agriculture as a means of generating economic value from otherwise vacant or underutilized space, then the equation is quite different; in fact, most urban farms in NYC occupy such sites. As such, it can be argued that urban agriculture is generally an additive, as opposed to substitutive, form of economic development, creating value from sites, which are not suitable or attractive for other uses. These sites include rooftops, which comprise a large percentage of the city's land cover, and represent an opportunity for property owners to extract rent from an otherwise unused space. It is also important to consider the indirect economic benefits of urban farming. These include effects on surrounding property prices, which have been shown to increase in the presence of community gardens, partially offsetting any loss of tax revenue from impeding development on such sites (Been and Viocu, 2007), and the extent to which urban agriculture contributes to other types of food-related economic activity such as food processing and food service. Certain parts of NYC, most notably Brooklyn, are experiencing a much-publicized surge of activity around small-scale "artisanal" food production and processing, which has economic impacts. To our knowledge no comprehensive study of such impacts has been done, although there are precedents for quantifying the economic benefits and multiplier effects of local food systems, for example in the work of Masi, Schaller, and Shuman (2010), who use the IMPLAN (Impact Analysis for Planning) modeling tool.

2.3.4 Public Health, Food Security, and Educational Benefits of Urban Agriculture

While the potential environmental and economic benefits of urban agriculture are wide-ranging, the primary focus of interest remains the production of food within, and for, urban communities and the effects on food access and health. NYC obesity and diabetes prevalence, at 23 and 9 percent respectively, are higher than national averages (Van Wye et al., 2008; NYC Department of Health and Mental Hygiene, 2008 and 2009) and have corresponding effects on medical expenditures, life expectancy, and quality of life (Dinour, Fuentes, and Freudenberg, 2008). Urban agriculture is perceived as one of many strategies to help alleviate these figures, because it represents an opportunity for city dwellers to increase their awareness of the food system, diet, and their effects on health while also increasing the supply of the healthiest foods. As is evident in Figure 2.8, which shows data for United Hospital Fund (UHF) neighborhoods, there is a correlation between obesity prevalence and fruit and vegetable consumption. Produce consumption impacts other health outcomes as well; people who eat fruits and vegetables three times or more a day are 42 percent less likely to die of stroke and 24 percent less likely to die of heart disease than those who eat them less than once a day (Bazzano et al., 2002). The neighborhoods in which obesity and diabetes levels are high - Harlem, the Bronx, far eastern Queens and the Rockaways, central Brooklyn, and northern Staten Island - have the lowest consumption of fruits and vegetables. In these places, less than one quarter of food retailers are likely to sell fresh food. A study conducted by the Department of Health and Mental Hygiene, the DCP, and the New York City Economic Development Corporation, found that the city faces a widespread shortage of neighborhood grocery stores and supermarkets (NYC DCP, 2008), and that approximately three million New Yorkers face high need for fresh produce, especially in low-income neighborhoods. Many New Yorkers live in areas where bodegas, pharmacies, convenience stores, and discount stores are the major food retailers; such establishments are often unable or unwilling to provide fresh produce due to the additional costs of storage.

By some measure, urban agriculture is already contributing to improved food security in NYC, and has the potential to increase access to fresh, healthy foods. Community gardens across the city are providing food to members and supplying local food banks with their produce. The Farming Concrete project reported 87,690 lbs. of vegetables were grown on just 67 gardens of the city's hundreds of community gardens in 2010 (Gittleman, 2010). Urban farms such as Added Value Red Hook and East New York Farms have CSA programs offering produce from their farms, while Eagle Street Rooftop Farm has a CSA, which is supplemented with produce from a farmer in the Hudson Valley (this may be the first CSA in the nation to be at least partially supplied by a rooftop farm). Farms and community gardens are also selling their produce at farmers markets, in some cases onsite (such as with Added Value Red Hook, East New York Farms, and others). The City is partnering with Just Food to establish five more farmers markets at community gardens. Many of these farmers markets also host regional producers from outside the city. These examples provide ample evidence of how urban agriculture is acting as a catalyst for larger food system change by providing facilities and logistical support for regional producers to gain access to urban consumers. Many of these community farmers markets are in areas where conventional grocery stores are reluctant to locate due to concerns about neighborhood income levels and demand.

Figure 2.8. 2009 Obesity Prevalence and Fruit and Vegetable Consumption in NYC, by United Hospital Fund Neighborhood (data from NYC Department of Health and Mental Hygiene, 2011).



If existing urban food production is already affecting food access in NYC, the potential for urban agriculture to contribute to food security is much greater. As discussed in Section 1.6, it is unlikely that, using current growing methods, NYC would be able to grow a large percentage of its overall fruit and vegetable needs. If we consider the needs and resources of particular communities within the city, however, a different picture arises. Many neighborhoods have a confluence of factors making urban agriculture a particularly attractive and effective means of addressing multiple challenges. These include poor access to healthy food retail, high prevalence of obesity and diabetes, low median income, and comparatively high availability of vacant and other available land. Neighborhoods fitting this pattern include East New York, Brownsville, Crown Heights, Bedford-Stuyvesant, and Bushwick in Brooklyn, the Lower East Side and East and Central Harlem in Manhattan, and Morrisania, Claremont Village, East Tremont, and Belmont in the Bronx, among others. These are also neighborhoods where the presence of many community gardens signifies community interest in and engagement with food production.

Increasing food security is more than just a matter of increasing local food production. Storage, processing, distribution, and retail are all critical components of ensuring fresh food access, and these components of the supply chain can pose a challenge to urban farmers. Very few urban farms have the capital necessary to build refrigeration space and purchase processing equipment capable of handling commercial volumes. These factors limit production capacity as urban farmers without adequate storage capacity must not only concern themselves with growing the food, but also with ensuring that they will have a market for produce available upon harvest. Some farms, such as Added Value Red Hook, are considering on-site refrigeration able to provide meat to the community and to have a greater retail presence. Others are beginning to establish arrangements to use church or school kitchens for processing on days when they are not in use. Another advantage of using these existing facilities is that they presumably already have the necessary food processing licenses and fees, which can be prohibitively expensive and difficult for small farmers to obtain. NYC also has huge potential for increasing commercial processing facilities, many of which could process produce grown in the city. This issue is addressed in the City Council's *FoodWorks* report, which calls for the development of new industrial space for food manufacturing businesses, among other recommendations (NYC Council, 2010). Increasing storage and processing capacity would also allow for food grown in urban farms to be available throughout the season and provide opportunities for farmers to increase profitability through value-added products.

Measuring the actual effects of urban agriculture on public health at a city or a neighborhood scale is very challenging, given the myriad extenuating factors and the long periods of time required for any intervention to have a discernible effect on chronic disease prevalence. While the health benefits of increased fruit and vegetable consumption are clear, the extent to which increased spatial access to them results in increased consumption is less well established (Boone-Heinonen *et al.,* 2011; An and Sturm, 2012). Short of longitudinal assessments of consumption changes or diet-related disease prevalence, the best approach to studying this issue would be to survey residents of a particular neighborhood before and after the establishment of an urban farm to discern reported changes in consumption habits. There are other means where urban agriculture could have positive public health outcomes, including increased opportunities for physical activity (this applies primarily to community gardens or other models that incorporate public participation) and impacts on mental health.

Another argument made in favor of urban agriculture is that it increases food system awareness and healthy eating among urban populations, and provides many opportunities for education. While it may be difficult to determine how such soft measures as "awareness" translate to actual behavior change, surveys of direct participants in urban agriculture activities (which might include on-farm volunteers or CSA subscribers) as well as those indirectly affected (such as residents of the surrounding community) establish how attitudes and knowledge of healthy eating change over the period of the farm's existence and could begin to answer some of these questions. Additionally, there is the related movement toward establishing gardens in schools to teach children about nutrition and other social and environmental topics. While this hardly represents "agriculture" in the traditional sense, the hope is that these programs will increase healthy eating behaviors and may even encourage an interest in farming as a career or in agriculture as a field of study. The citywide school garden initiative "Grow to Learn" has 202 gardens in their program currently and aims to increase this number by over 100 (Otterman, 2010).

2.4. The advantages and disadvantages of small scale production

In this section, we evaluate the advantages and disadvantages of the scale of production typically associated with urban and peri-urban farming, and discuss means through which the potential disadvantages can be addressed through alternative production and distribution mechanisms.

2.4.1 Disadvantages

Operating on a small scale, i.e., producing a smaller than average output volume per farm, involves distinct challenges to entering conventional distribution networks. The fixed costs can be too high to justify the involvement of large-scale national food distributors, in addition to their general requirements for consistency in product volume and quality. This typically limits small-scale farms to local retail outlets, and while such local networks may indeed have substantial benefits for small-scale farms, (Section 2.4.2, most food products pass through the conventional national channels. According to the USDA Census of Agriculture, the total value of farm products was little over $280 billion in 2009, of which only $4.8 billion was generated through local sales (Low and Vogel, 2011).

Exclusion from traditional distribution channels also reduces the possibility of the small-scale farmer to protect against various forms of risk, including price risk and production risk. Price risk corresponds to the uncertainty over the price that the product will command at the time of harvest, and production risk involves the possibility of the farmer not meeting expected yields (e.g., due to weather conditions or pests). There are, in broad terms, three possible ways to mitigate or manage these risks: financial hedges in a commodities market, insurance coverage, and contract farming. Agricultural staple commodities, such as wheat, soybean and corn are traded on liquid markets with standardized futures and forwards contracts. The Federal Crop Insurance Corporation offers protection for an array of different crops and for a variety of contingencies (covering primarily large losses) through various private intermediaries. Total nominal liabilities covered by the FCIC have grown by 380 percent over the past decade, and in 2010 the total crop value insured was $78 billion (USDA RMA, 2012), indicating increased willingness to mitigate price and production risks.

According to a recent USDA report (O'Donoghue, 2011), almost ten percent of U.S. farmers in any given year have entered into a marketing contract of some kind. These contracts typically stipulate the product quantity and quality as well as the time of delivery and price (or price formula). Agreements like these inherently mitigate price risk, and they may contain provisions regarding production risks. Since the product is usually intended for the primary food distribution network, the contractor typically specifies procedures during the growing phase for quality assurance. As explained in Hueth, Ligon *et al.* (1999), assuring contract compliance on behalf of the farmer requires additional costs, either in the form of labor for inspections or investment in monitoring equipment. For small-scale producers, especially those who grow specialty crops, hedging price risk in financial markets is usually not an option either because individual volumes are too small or due to lack of sufficient trading of the produce. Furthermore, obtaining crop insurance for specialty crops grown on smaller plot sizes is likely more difficult due, in part, to the sometimes very detailed quality assurances mentioned.

In terms of total value output, the U.S. agricultural system has seen a substantial shift towards larger farms over the past 25 years. In 1982, very large farms (classified as those with gross cash farm income over $1 million per year) accounted for 27 percent of all agricultural sales. In 2007, that fraction had risen to 59 percent (Hoppe *et al.,* 2010). According to the same report, this shift to larger farms is due to increased profitability, which in turn is explained to a large extent by lower relative labor costs, as demonstrated in Figures 2.9 and 2.10. Figure 2.10 also shows the tremendous economies of scale for labor attainable in agricultural systems, a factor which cannot be disregarded when considering small-scale farming. It should be mentioned that the numbers in Figure 2.10 are averages and the organizational structure of these smaller farms is highly diversified, covering both lifestyle-oriented, non-commercial farms as well as farms that commercially market their products.

Figure 2.9. Profitability of farms by size classified by gross cash farm income (from Hoppe et al., 2010).

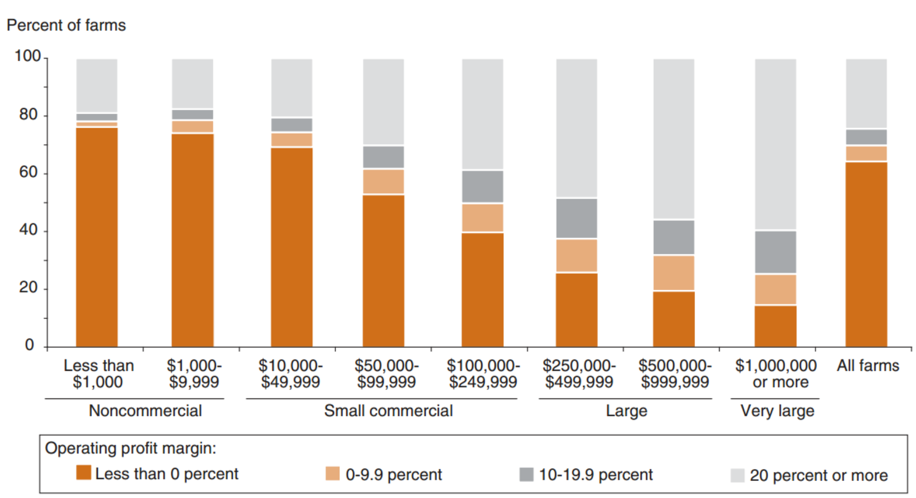
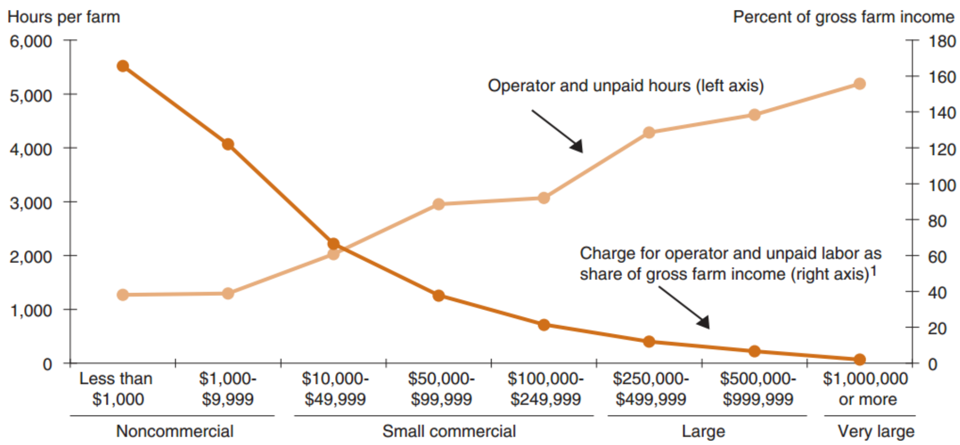
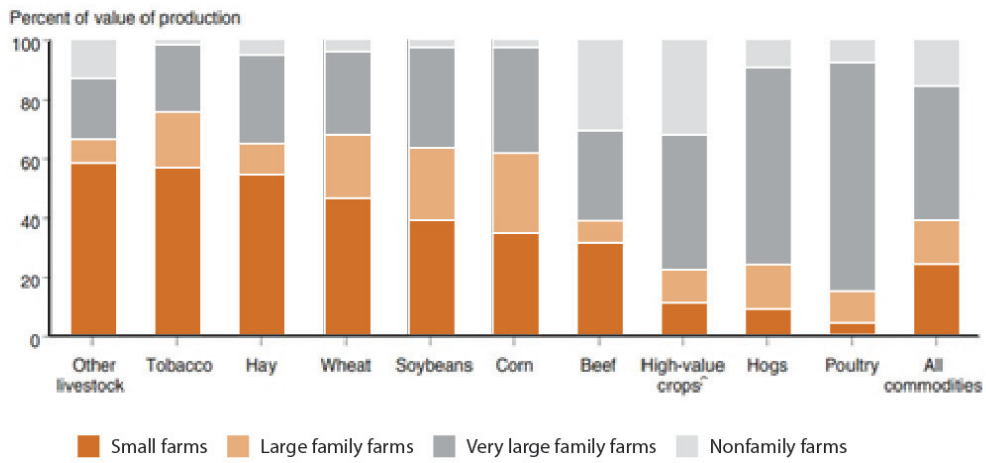


Figure 2.10. Average amount of labor required and the cost as share of gross farm income. With smaller scale farms typically being family operated, wages are often not paid regularly but withdrawn as needed. The term 'operator and unpaid hours' therefore includes all labor, paid and unpaid (from Hoppe, MacDonald et al., 2010).



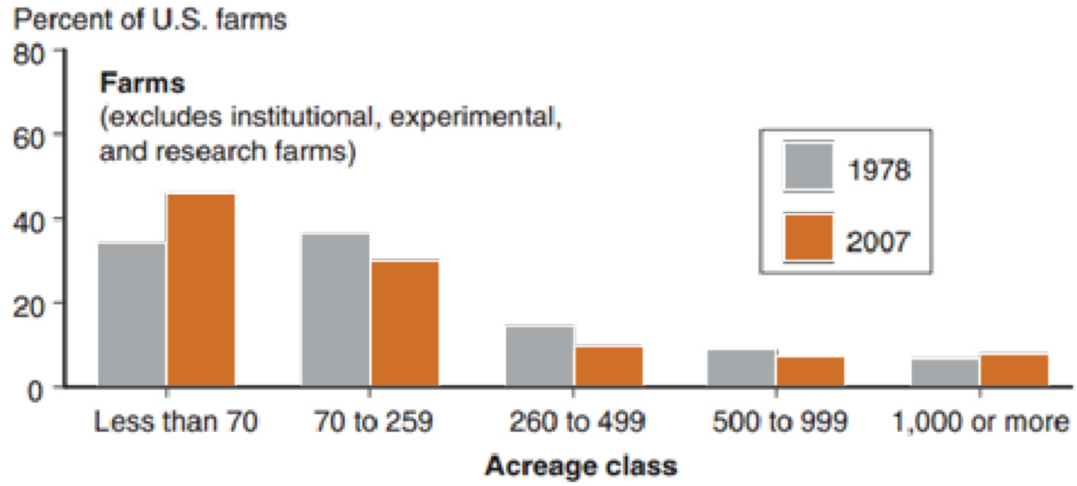
Farming in an urban or peri-urban setting often involves relatively high opportunity costs for land and thus high-value crops (fruits and vegetables) are likely product candidates to ensure economic viability. However, the current average size of vegetable farms (including melons) in the U.S. is 228 acres (Arita *et al.,* 2012). This figure is considerably larger than what we are considering as small scale farming in this context. Indeed, as shown in Figure 2.11, which shows the distribution by scale of producers of various agricultural products, high-value crops are predominantly grown by either very large family farms or by non-family farms and only to a lesser extent by small farms. One explanation for this trend is that these products, to a greater degree than other staple crops, require full-time labor and most small farms are operated merely part-time with the operators relying on off-farm income to sustain their livelihoods. Additionally, the handling and marketing of these crops are more involved, further requiring full-time commitment and a larger scale of production (Hoppe *et al.,* 2010).

Figure 2.11. Distribution of value over different producers for various crops (from Hoppe et al., 2007).



In contrast to the general trend towards larger farms in the past 30 years, it bears mentioning that over the same period the total number of smaller farms has increased, as is evident in Figure 2.12. A cultural movement driven by urban population centers that for various reasons, seeks alternatives to the general trend of centralization in the food system partially explains this trend. Most likely, sustaining this trend requires further adoption of localized distribution and marketing networks as described in Brown and Miller (2008). Most local food producers rely, to a great extent, on direct-to-consumer channels including farmers markets, on-farm stores, roadside stands and CSA agreements (Low and Vogel, 2011). Except for CSA agreements that include delivery to the consumer, all these channels require a dedicated trip by the consumer for only a limited number of products, compared to the variety found in a supermarket. To avoid exacerbating the problem of 'last mile' distribution in terms of energy consumption, a substantial scale-up of the production of locally grown food requires some form of aggregation closer to the end consumer. Many farmers markets offer a limited selection of products, thereby attracting primarily dedicated customers. Aside from the issue of siting, which is a challenge for space-constrained NYC, the aggregation of more products and consequent increased customer demand would require increasing direct participation from farmers themselves, which might not be a possibility for many growers. Disregarding the subscription and delivery option of CSAs, a scale-up of local food production likely requires some form of integration with existing channels, at least at the consumer level. If, or when, such integration occurs, the premium that locally grown products currently command risks being diluted, which ultimately may limit the market.

Figure 2.12. Distribution of farm sizes in the U.S. (from Hoppe, MacDonald et al., 2010).



Unless local distribution networks are appropriately adopted and expanded, small-scale farms will face difficulty bringing their products to market. Furthermore, typically being excluded from traditional distribution channels, small-scale farms face difficulty protecting against risks such as price and production risk. Perhaps partially as a consequence of limited marketing opportunities, smaller farms are on average less profitable than larger farms. Another explanation for the difference in profitability between large and small farms is the possibility to draw on economies of scale when it comes to labor. Small farms cannot rely on mechanization to the same degree and will therefore see lower labor productivity.

2.4.2 Advantages

As explained in Section 1.5, agricultural operations on smaller plot sizes make capital-intensive, mechanized equipment difficult to justify from an economic standpoint; instead, operations must rely to a higher degree on manual labor. In such regimes, the growing practices can and should be considered from the perspective of monoculture vs. polyculture growing practices. With current technology, mechanized equipment is ill suited to accommodate the production of intercropped cultures, whereas manual labor should have little difficulty handling two (or more) crops grown side by side. Among the benefits of growing in polycultures are herbivore suppression, decreased use of pesticides, increased resistance to disease, and increased soil quality with better water maintenance (Altieri et al., 1983; Thrupp, 2000; Letourneau et al., 2010). Furthermore, a polyculture including nitrogen-fixating legumes will reduce the need for synthetic fertilizers, and thereby reduce both costs and the carbon footprint of the operation (Cruse et al., 2010; Pelzer et al., 2012) (It should be noted that this may not be the case in greenhouses, where the competing climatic needs of separate species may decrease overall efficiency of production). In addition to these environmental and cost benefits, crop diversity, when employed optimally, can increase the revenues per unit area of cultivated land. Planting different crops side-by-side has the potential to make the land 'biologically over-yielding,' i.e., the total crop yield in a polyculture exceeds the yield from the same amount of land where each crop is grown as a monoculture in the same proportions. Polyculture cultivation may not be feasible in greenhouse systems, owing to the different climatic conditions necessary for growing different crops. Furthermore, the various combinations of crops that render such an outcome feasible also have the possibility of being economically over-yielding, meaning that the land output value also exceeds the monoculture counterpart. Counteracting these advantages is the apparent need to increase labor expenditure, as discussed below. The optimal scale will ultimately depend on the crops grown as well as prevailing wage rates.

A potential advantage of urban or peri-urban farming (and therefore by necessity also small scale farming) is increased consumer awareness of how food systems work. This could in turn lead to changing quality standards, which could have a substantial impact on the bottom line for the growers. According to FAO (2011), around 20 percent of fruits and vegetables grown in the U.S. are discarded on the farm. The majority of the discarded produce is perfectly edible but is rejected for cosmetic reasons. Emotional proximity between farmer and end-customer could therefore lead to reduced waste in the system. Additionally, increased awareness of local agriculture could lead to a greater acceptance of the seasonality of most produce. Extending beyond local food outlets and a more stable revenue stream for local farmers, this could lead to a decrease in the demand of off-season products that incur greater energy penalties to supply year round.

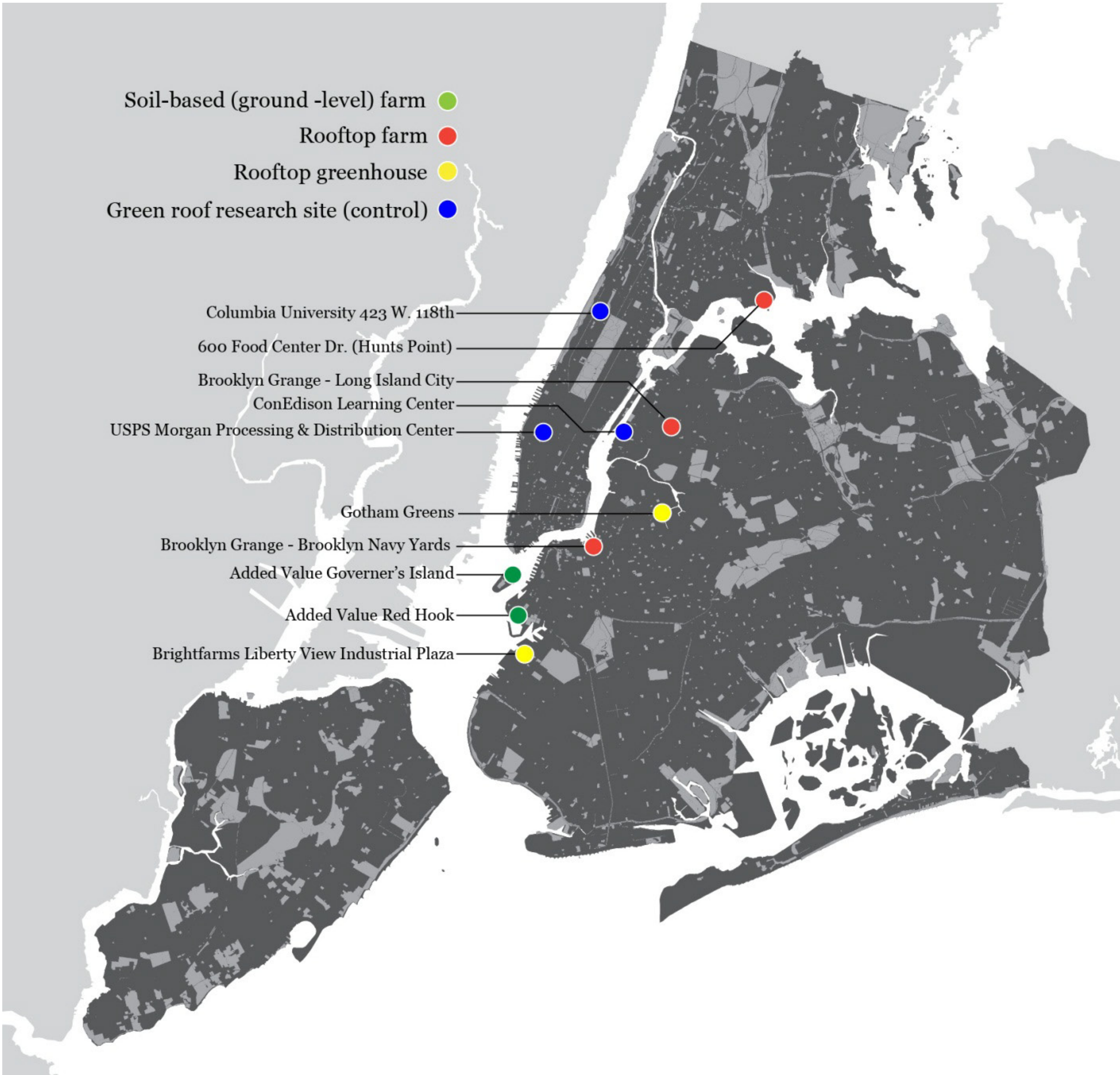
As explained in Section 2.4.1, small-scale farms face a greater difficulty compared to larger farms to protect against risk using conventional means. However, the opportunity for resolving price risk and to some extent, also production risk by entering into marketing contracts directly with the end-consumer is more tractable on a local scale. The smaller production volumes more closely match the demand from single local customers, such as restaurants or markets, making the logistics manageable without a third party. Shortening the value chain between producer and consumer potentially voids the need of strict quality assessment, leveraging personal relationships instead, and thereby avoiding some of the burdens of typical marketing contracts. CSA agreements are slightly different from contract farming in that the customers subscribe for produce without necessarily determining what and how it is grown. By paying a subscription fee the customer is entitled to a certain fraction of farm output. This, at least in the short term, completely transfers both production and price risk from the farmer to the customer. Naturally, such a risk arrangement comes with a price, and in a national survey to CSA farmers in 2001, only 46 percent of respondents indicated that they were happy with CSA revenues (Brown and Miller, 2008). However, in addition to the recent growth of the number of CSA farms in the U.S. recently, a large fraction (more than 25%) of the operators of these farms have no previous farming experience at all (Woods *et al.,* 2009). New to the profession, the risk mitigation embedded in CSA agreements is likely an attractive marketing option.

Small-scale farming is likely to rely more on manual labor than capital intensive mechanized equipment. This raises the ability to grow in polycultures which, depending on combinations of product grown, can reduce the need for synthetic fertilizers as well as pesticides. Such a strategy might lower the environmental footprint of the operation as well as the cost of operation. Furthermore, growing food in close proximity to the end-consumer can potentially increase awareness of how food systems work. This can lead to reduced amounts of waste, due to altered standards regarding cosmetic appearance of product, which helps the bottom line of the small-scale farmer. In addition, a leaner supply chain with few, if any, middlemen allow the producer to enter into production contracts directly with the end-consumer, offering both a different marketing option and form of risk protection.

2.5. Identify potential sites in New York City for future testing and research of alternative agricultural practices

Throughout the course of this work, a number of sites in the NYC area that could be used for future research on many of the issues outlined in this report have been identified. Ideally, several urban and peri-urban farms of different types would be studied over the same multi-year period, and input-to-output ratios tracked, to determine which approaches yield the best results over time. As mentioned in Section 2.1, researchers have started to gather some of this information at the Stone Barns Center greenhouse, and this data will be useful in assessing their particular approach to small-scale peri-urban agriculture. Within the city, there are a number of commercial-scale farms that would yield useful data if studied over a period of time. Of particular interest are operations that are either in the planning phase, nearing completion, or recently completed, as these farms are likely to have the most comprehensive record of the start-up material and energy inputs necessary to reach operational capacity. These include the recently completed 45,000 ft^2 rooftop farm constructed by Brooklyn Grange in the Brooklyn Navy Yards (the Urban Design Lab will be the monitoring environmental performance of this site, including weather, stormwater runoff quantity and quality, evapotranspiration, CO_2 sequestration, and local air particulate counts, and comparing results to data gathered from existing conventional green roofs on the US Postal Service Morgan Mail Processing Facility in Midtown Manhattan and the Columbia University green roof on 118th St.). Other pending projects that could provide opportunities for future data collection are the 100,000 ft^2 rooftop greenhouse to be constructed on the Liberty View Industrial Plaza building in Sunset Park, Brooklyn (see description in Section 2.3.1.3 above), and a 200,000 ft^2 rooftop farm being planned for the Hunts Point neighborhood in the Bronx. As far as soil-based farming is concerned, the best sites for future research are likely to be the two farms operated by Added Value, in Red Hook, Brooklyn, and on Governor's Island, respectively, as they are two of the larger urban farms in the city. The site in Red Hook was constructed on top of an impervious surface (making runoff measurements more feasible), and they are run by a well-organized operation with many years of experience. (See Figure 2.13 for a map of these various locations.)

Figure 2.13: Potential sites for research on soil-based, rooftop, and rooftop greenhouse agriculture in NYC.



2.6. Establish potential scales and distribution of operation

Considering the wide variety of agricultural products, small-scale farming will naturally involve different management practices. Furthermore, with the overwhelming bulk of food products still moving through conventional distribution channels (and typically originating at large-scale farms) it is unlikely that there is an optimal scale of either production or distribution. Acknowledging this uncertainty, we will discuss two small commercial operations with very different production and distribution models; Corbin Hill Farm in Schoharie County, NY and Gotham Greens in Brooklyn, NY.

Founded with the purpose of affordably supplying fruits and vegetables to under-served areas in NYC from a network of local farmers in the Hudson River valley, Corbin Hill Farms is a CSA, which brings locally grown produce to consumers in the city. The individual farms supplying the program are each less than 100 acres (with some much smaller than that), as compared to the U.S. average of just over 400 acres. The farmers deliver their products once a week to a local aggregation point within 10−15 miles of the farm where they are packaged in baskets and delivered to various points in the city for pick-up by consumers. This form of CSA offers very limited amount of retail and distribution logistics while still bringing a reasonably differentiated volume of products to the end consumer.

In contrast to the previous example, Gotham Greens is a rooftop greenhouse operation growing produce hydroponically within the city boundaries. In its greenhouse (<1 acre), a smaller selection of higher value products (primarily lettuce) are grown year-round in a controlled environment. Cultivation of a very limited number of crops allows for a high degree of product consistency and a focus on quality, which justifies their price premium. Gotham Greens delivers its products directly to several conventional retailers in the city. This gives the grower exposure to a large group of end-consumers without going through a central aggregator/distributor.

These two examples show the possibility of operating on a relatively small scale and utilizing unconventional distribution channels. While direct-to-consumer outlets such as farmers markets are, or have been, employed by both the farmers in the Corbin Hill Farm CSA network and by Gotham Greens, such channels are likely to have limited capacity for expansion given the requirement of direct participation from producers. As these examples demonstrate, it is possible for small-scale growers to market their products without engaging in direct retail or going through conventional channels by developing innovative distribution methods directly related to the scale of their operation.

Conclusion

While the scope of this study is very wide-ranging in its attempt to delineate the myriad variables, which determine energy use in agriculture and how they are affected by scale of operation, there are some broad themes, which have been consistently reinforced by the analysis. The first important conclusion, by no means unique in comparative life-cycle analyses, is that the impacts of scale in a given system, in this case agriculture, must be evaluated throughout the product life-cycle. Specifically, the scale of the production system will impact the scale and structure of subsequent links in the value chain, including processing, distribution, and retail, which will have substantial impacts on total system energy use. There is much more research to be done on these factors for a more accurate and informed picture of the differences between urban and more conventional farming techniques. Direct measurement of inputs, yields, and waste from multiple representative farms along the entire distribution chain, would be useful data for comparisons.

The outcomes of this analysis also suggest that there may indeed be significant advantages to smaller-scale agriculture within or close to urban areas, as measured by the ratio between the sum of on-farm material inputs and direct energy use from farm-to-retail, and the volume of product obtained by consumers. These potential advantages are due primarily to fewer on-farm inputs of fertilizer and pesticides, more intensive (and higher yielding) growing practices, more targeted transportation and distribution systems, and less mechanization at all stages of the value chain. As with other sectors of our economy, however, environmental performance and resource use are not aligned well with commercial profitability. Energy costs are one of the many factors, which determine economic viability. On that front, there are distinct challenges faced by smaller operations primarily because substituting labor for mechanized processes usually increases costs substantially. Other economic challenges include higher land values in and around densely populated areas and the difficulties inherent in finding reliable markets for smaller volumes of product. Further, climate imposes limitations on year-round cultivation particularly in the Northeast. Some urban and peri-urban farmers are devising creative ways of maximizing yields and establishing direct-marketing channels to address these challenges. Other farmers are focusing more on the ancillary benefits to the environment and community education and engagement by operating in a non-profit model. These approaches can be replicated, but future expansion is inherently limited because they are small scale and not a viable substitution for the dominant existing food supply system to urban areas. They may, however, be important in adding resilience to and increasing food security by supplementing the supply of specific healthful foods in otherwise underserved areas. Beyond this, the multiple ancillary impacts of urban and peri-urban agriculture, including environmental and social benefits, justify continued support from policymakers and the public.

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Sustainable Urban Agriculture:
Confirming Viable Scenarios for Production

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