ISSST 2022

Presenter: Darlene Steward, National Renewable Energy Laboratory
Controlled Environment Agriculture - Farming and Food Access for Healthy Diets

Theme: IHPS-3
Session: Neighborhood, Community, and City-Level Changes

Co-Authors;

Greg Avery & Jianyu Gu (NREL)

Acknowledgements;

James McCall and Taylor Uekert (NREL)

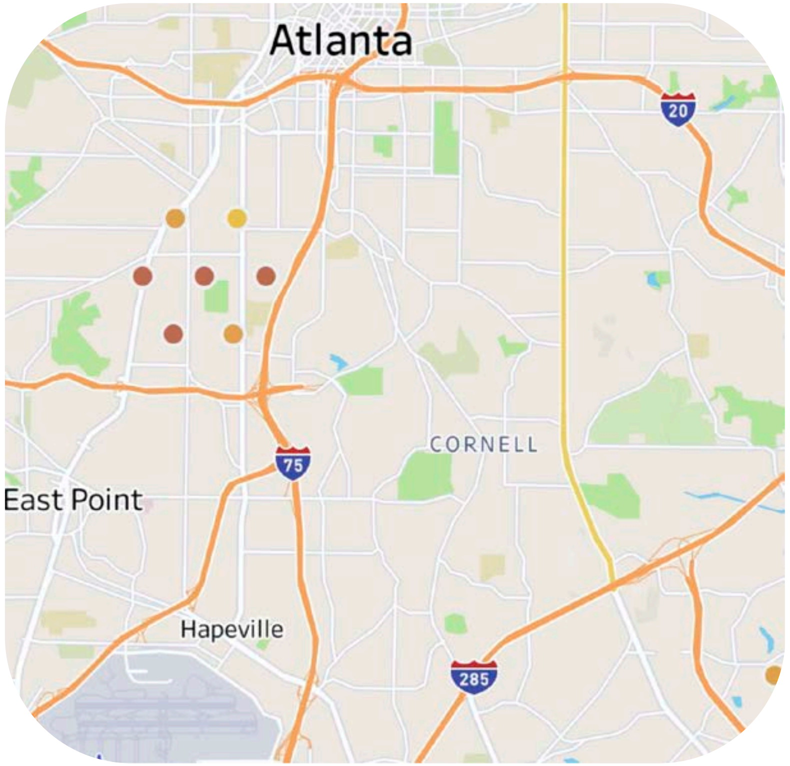
Joe Cresko (DOE)

Could growing some vegetables in controlled-environment vertical farms mitigate food system environmental impacts and improve food access?

Progress Report on Community Vertical Farming.

Outline

- Scope of this study
- Overview of current vegetable production versus vertical farms
- Current vegetable production resource use
  - Focus on water
  - Transport and on-farm energy
- Vertical farm model
- Case study; vertical farms in Atlanta
- Takeaways and future research



Scope of this study:

Fresh vegetables for a healthy diet that can be grown in Vertical Farms (VFs).

The modeled VFs are within walking distance for people who currently live more than a mile from a grocery store.

Per capita total fresh vegetable availability for a healthy diet. Total = 43 kg/person/year.

Dark Green		(kg/year)
broccoli	●	1.87
collard greens	●	0.09
escarole	●	0.03
kale	●	0.15
leaf lettuce	●	3.26
mustard greens	●	0.08
spinach	●	0.58
turnip greens	●	0.03
Total		**6.09**

Red & Orange		(kg/year)
bell peppers	●	3.9
carrots		6.0
chile peppers	●	1.8
pumpkin		0.9
squash		2.1
sweetpotatoes		1.6
tomatoes	●	17.7
Total		**33.9**

Other		(kg/year)
artichokes		0.3
asparagus		0.6
brussels sprouts	●	0.5
cabbage	●	2.8
cauliflower	●	0.7
celery		2.0
cucumbers	●	3.4
eggplant		0.3
garlic		0.8
head lettuce	●	5.9
misc. vegetables		1.0
mushrooms		1.7
okra		0.2
onion		8.2
other vegetables		0.9
radishes		0.2
snap beans		1.7
Total		**31.3**

Starchy	(kg/year)
green peas	0.2
lima beans	0.0
potatoes	20.3
sweet corn	2.0
Total	**22.6**

Grown in VFs in this analysis. ●

NREL Analysis

Sources; "USDA ERS - Food Availability (Per Capita) Data System" 2020; Dieter and Linsey 2017; USDA 2020; "USDA/NASS QuickStats Ad-Hoc Query Tool" 2021

How would transitioning to a healthy diet and moving vegetable production to VFs affect the food system?

Current Food System

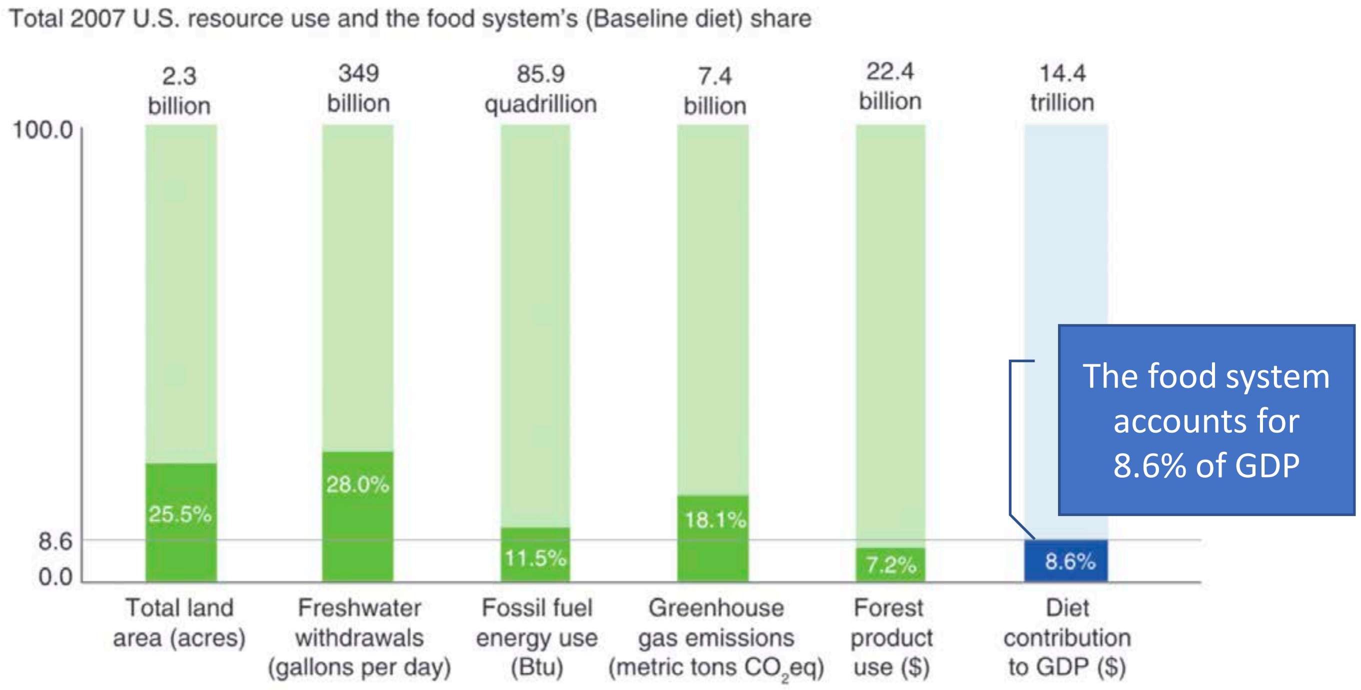
- Energy intensive
  - Energy use is distributed along the supply chain
  - Fossil fuel intensive
- Water intensive
  - Vegetable production is one of the most water-intensive segments of the food system
- Land intensive
  - Production is concentrated in a few states

VF Food Production

- Energy intensive
  - Energy use is concentrated at the farm
  - Primarily electricity
- Low water use
- Requires very little land
  - Production is distributed
  - Production is closer to consumers

The observed (baseline) U.S. diet requires intensive use (i.e., greater than the food system's share of GDP) for all categories of resource use except forest products

Estimated annual resource use in the Baseline diet across five categories, 2007



Btu=British thermal units. GDP=gross domestic product.

Note: Baseline diet is measured from the 2007–08 National Health and Nutrition Examination Survey (NHANES) (USDHHS CDC NCHS, 2013a)—a nationally representative survey of food intake by all Americans ages 2 and above.

Source: USDA, Economic Research Service.

Source: Canning et al. 2020

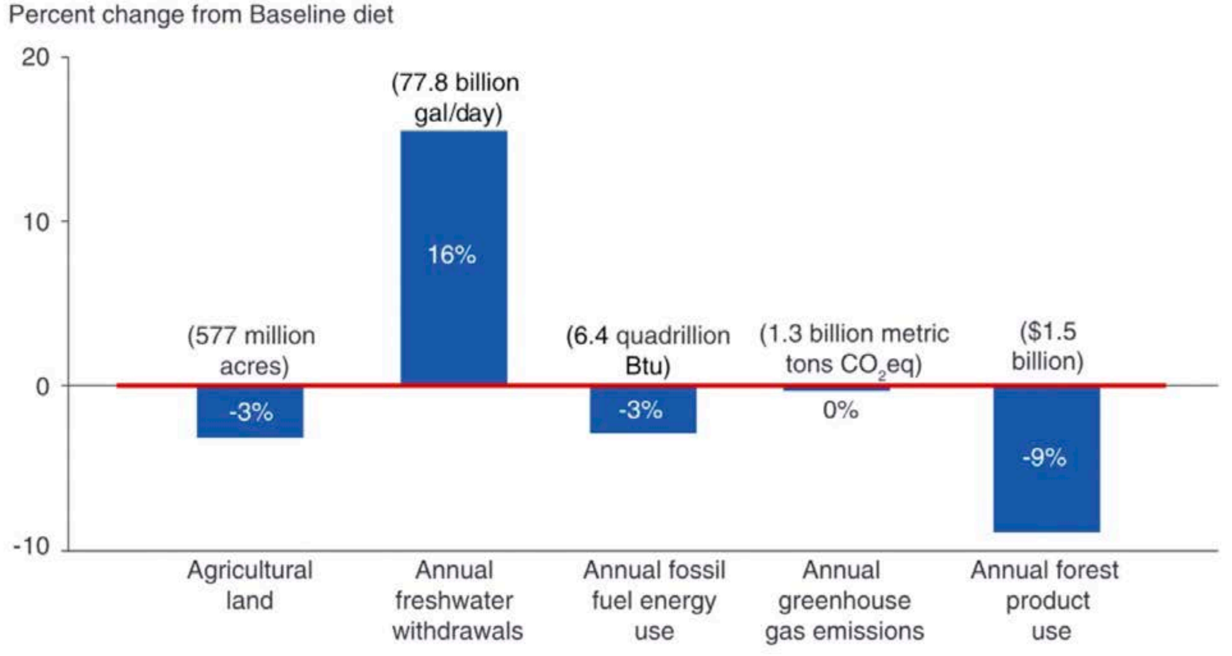
Americans would have to double their consumption of fruits and vegetables to transition to a healthy American diet (HAD)

U.S. Department of Health and Human Services and U.S. Department of Agriculture 2015

Transitioning to the HAD would reduce resource use in all categories except freshwater withdrawals

Canning et al. 2020

Estimated percent change in resource use going from Baseline to Healthy American diet



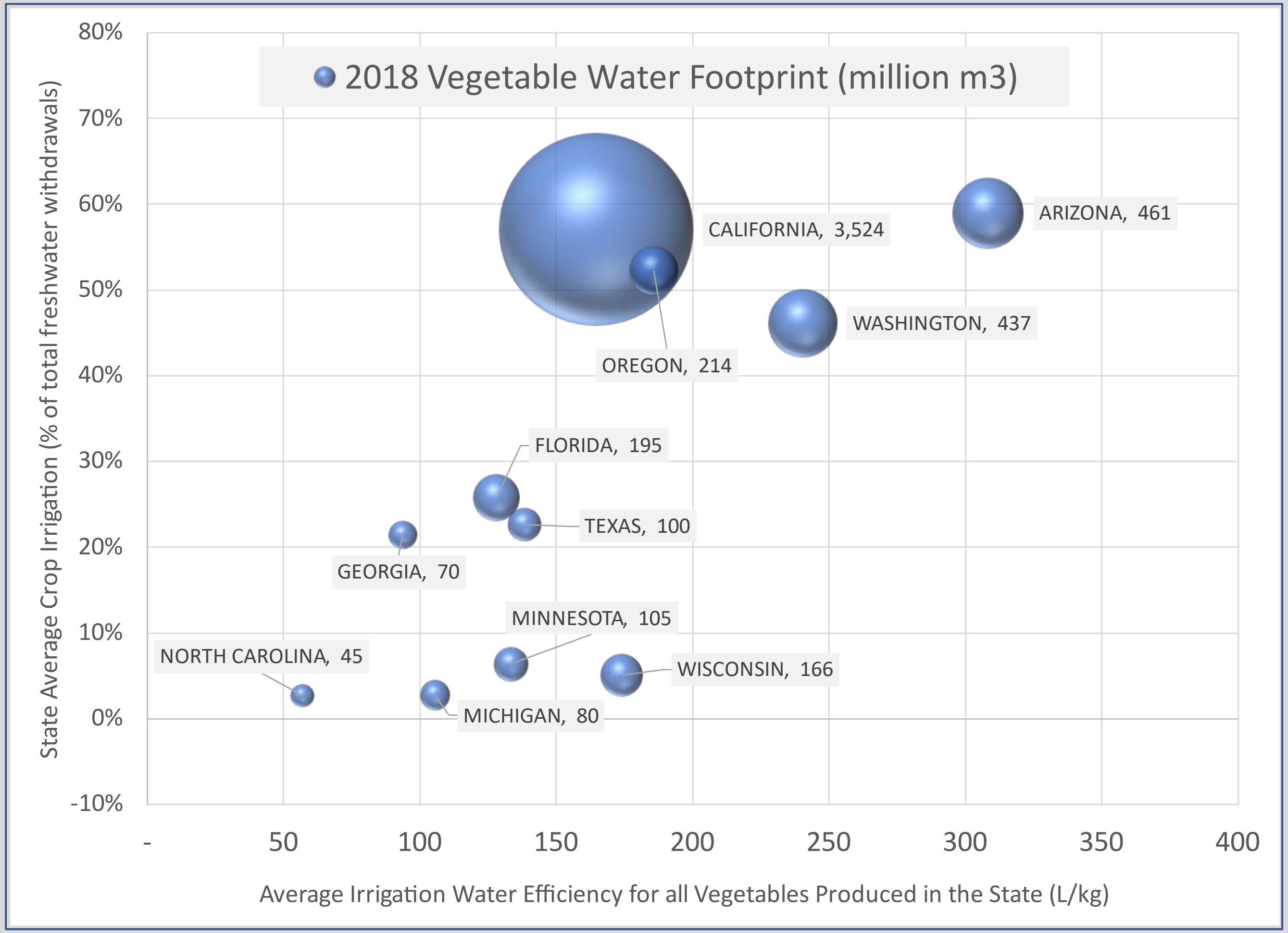
Btu = British thermal units. Note: Baseline diet is measured from the 2007–08 National Health and Nutrition Examination Survey (NHANES) (USDHHS CDC NCHS, 2013a)—a nationally representative survey of food intake by all Americans ages 2 and above. All diets are linked to the annual 2007 U.S. personal consumption expenditures on food (BEA, 2015). Healthy American diet is from a model that estimates the most likely food intake by all Americans in the 2007–08 NHANES sample who are meeting all 2010 *Dietary Guidelines for Americans* (USDA and USDHHS, 2010).

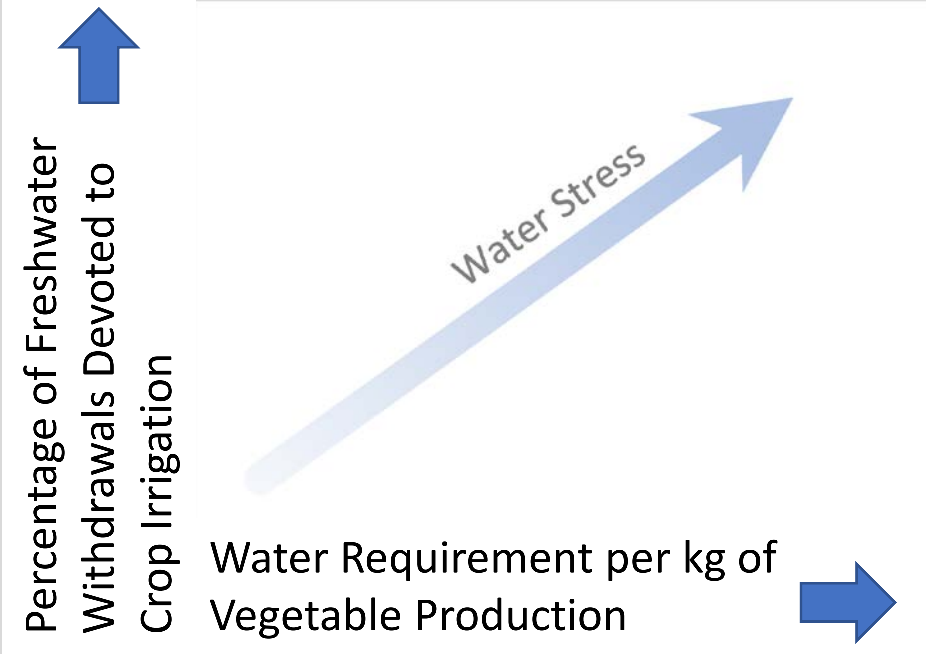
Source: USDA, Economic Research Service.

Source; Canning et al. 2020

Current ➢ HAD **reductions** in calories
- Sugars, sweets, & beverages -67%,
- Fats & oils -94%,
- Meats -24%,
- Grain products -9%

Current ➢ HAD **increases** in calories
- Legumes & nuts +173%,
- Fruits +101%
- Vegetables +107%
- Dairy +63%





Most vegetables are grown in water-stressed regions in the western United States. Transitioning to the HAD would increase annual freshwater withdrawals by 16%, primarily for increased vegetable production.

Moving some vegetable production* to distributed VFs would reduce water stress in vulnerable regions and reduce overall water use for vegetable production by 50%.

*Fresh vegetables amenable to indoor production (see slide 5)

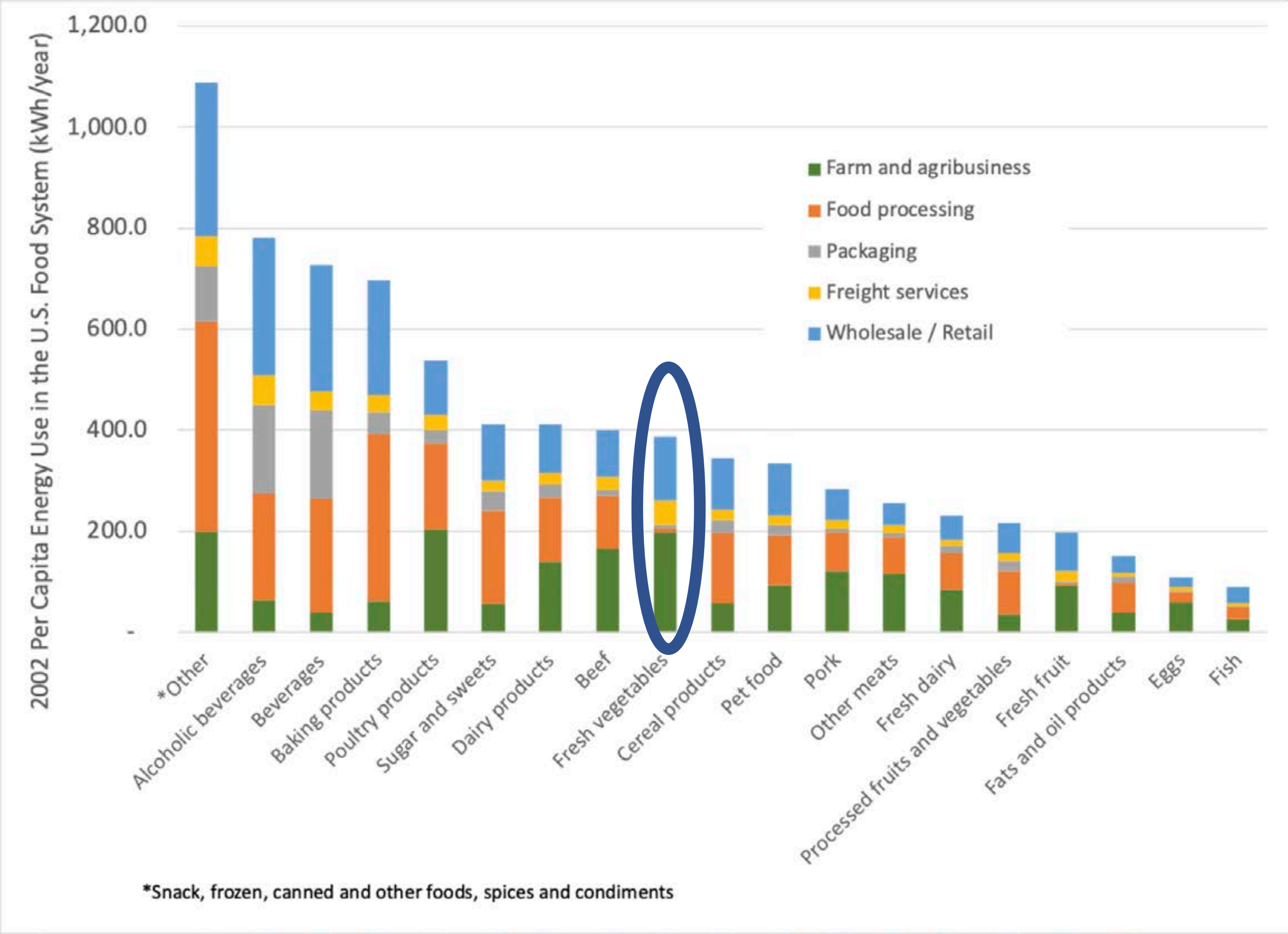
Sources; Canning et al. 2010; Canning, Patrick and Mentzer Morrison 2020; Peters, Wilkins, and Fick 2007; Canning et al. 2020; “USDA ERS - Food Availability (Per Capita) Data System” 2020; Dieter and Linsey 2017; USDA 2020; “USDA/NASS QuickStats Ad-Hoc Query Tool”; Sarah Rehkamp and Patrick Canning 2021; NREL analysis.

Per capita, the supply of fresh vegetables ranked third-highest in consumption of both on-farm energy and energy for freight services in 2002.

The current per capita supply of fresh vegetables requires;

- 20 m^2 of land
- 400 kWh of energy
- 10,000 L of water

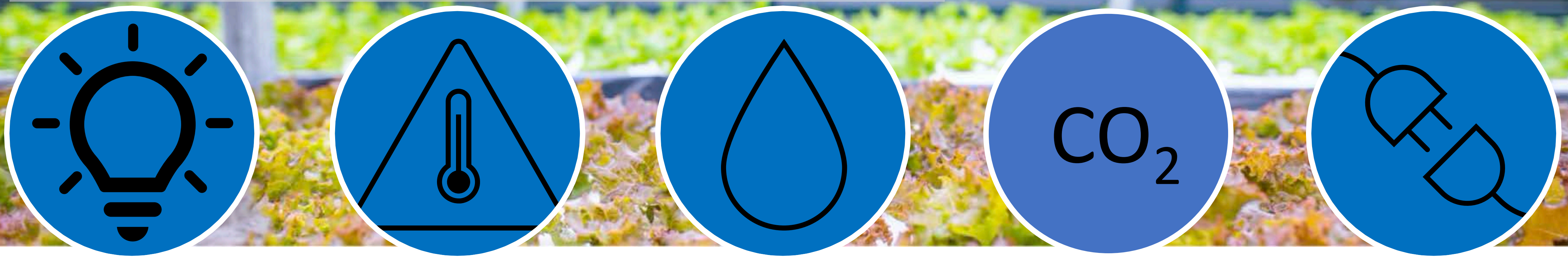
Sources: Canning et al. 2010, ("USDA ERS - Food Availability (Per Capita) Data System" 2020), ("USDA/NASS QuickStats Ad-Hoc Query Tool" 2021



Per capita distribution of energy use among food categories and supply chain stages (kilowatt-hours per year [kWh/year]) in 2002.
Source: Canning et al. 2010; NREL Analysis.

Energy is used in VFs to maintain optimal growing conditions.

. Photo from iStock-1152223992



Lighting

Modeled system; high-efficiency light emitting diode (LED)

***6.4 kWh/kg**

275 kWh/person/yr

Heating, Cooling & Humidity Control

Modeled system assumes integration of heating and cooling systems with the rest of the building.

***3.1 kWh/kg**

133 kWh/person/yr

CO_2 concentration

Slightly elevated CO2 concentrations through integration with an occupied building

0.2 kg CO2 required/kg

(not modeled as an input)

Mechanical

Energy is used for mechanical and control equipment.

0.1 kWh/kg

4.3 kWh/person/yr

* High variability in literature values

Sources; Hanford 2004; Martin, Poulikidou, and Molin 2019; Avgoustaki and Xydis 2020; Barbosa et al. 2015; Nelson and Bugbee 2014; Olvera-Gonzalez et al. 2021; Sanyé-Mengual et al. 2018; (Adenaeuer 2014; O'Sullivan et al. 2019; Benis, Reinhart, and Ferrão 2017a; Despommier 2013; Benis, Reinhart, and Ferrão 2017b; Van Ginkel, Igou, and Chen 2017; Graamans et al. 2018; Hanford 2004; Bao et al. 2018

Three or more farms would be needed to supply vegetables within walking distance of low-access residents in the circled tract

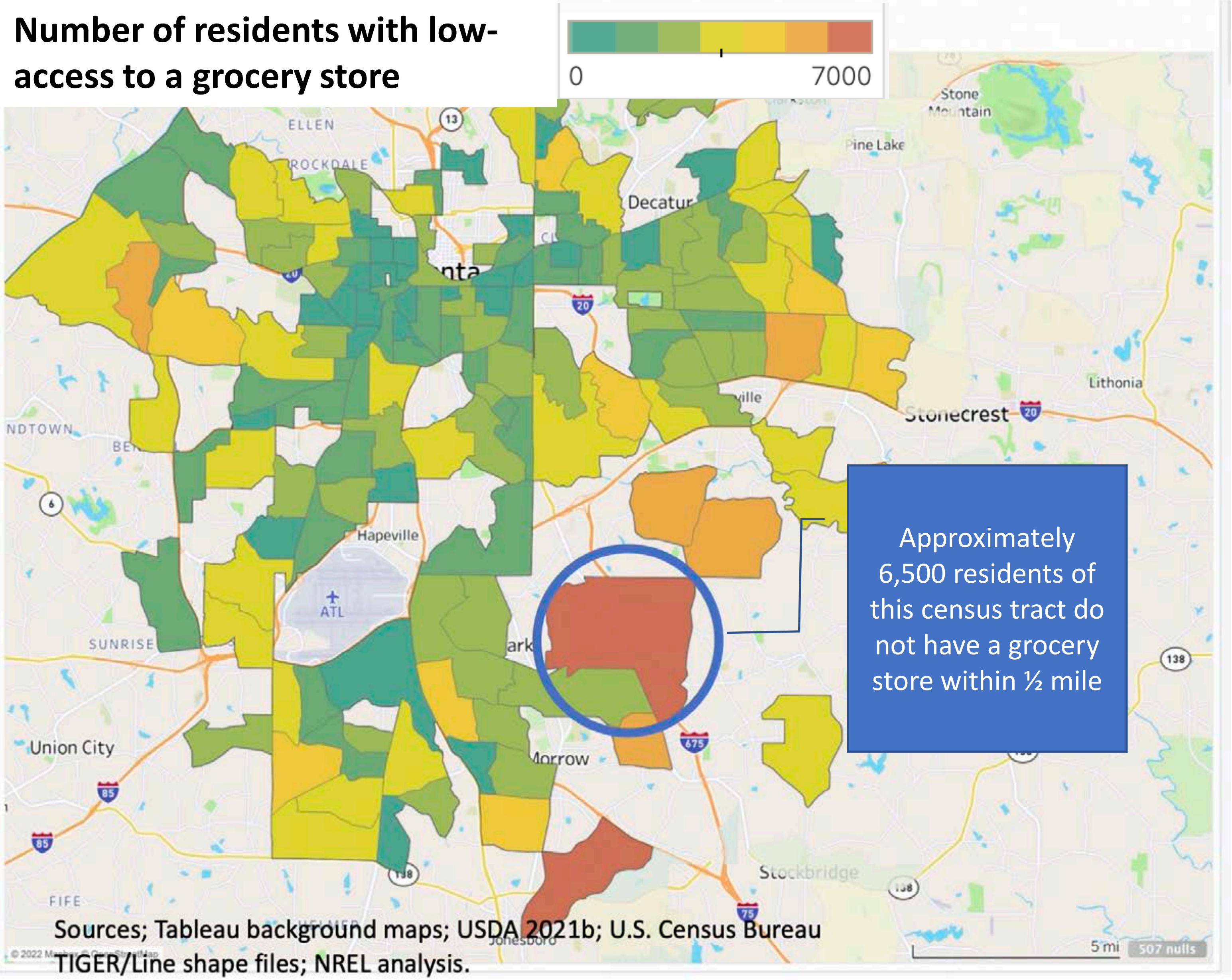
Per Capita Modeled Values for HAD fresh vegetables;

- Electricity; 410 kWh.
- VF footprint; 0.64 m^2.
- Water Requirement; 340 liters

VF production of a subset of fresh vegetables would reduce overall water use for vegetable production by 50%

Sources; Batstone et al. 2015; Cai, Park, and Li 2013; Ye et al. 2020; Theregowda et al. 2019; Wu and Vaneeckhaute 2022; Perera and Englehardt 2020; Rahimi et al. 2019; Van der Hoek, Duijff, and Reinstra 2018; NREL analysis

Number of residents with low-access to a grocery store



Sources; Tableau background maps; USDA 2021b; U.S. Census Bureau TIGER/Line shape files; NREL analysis.

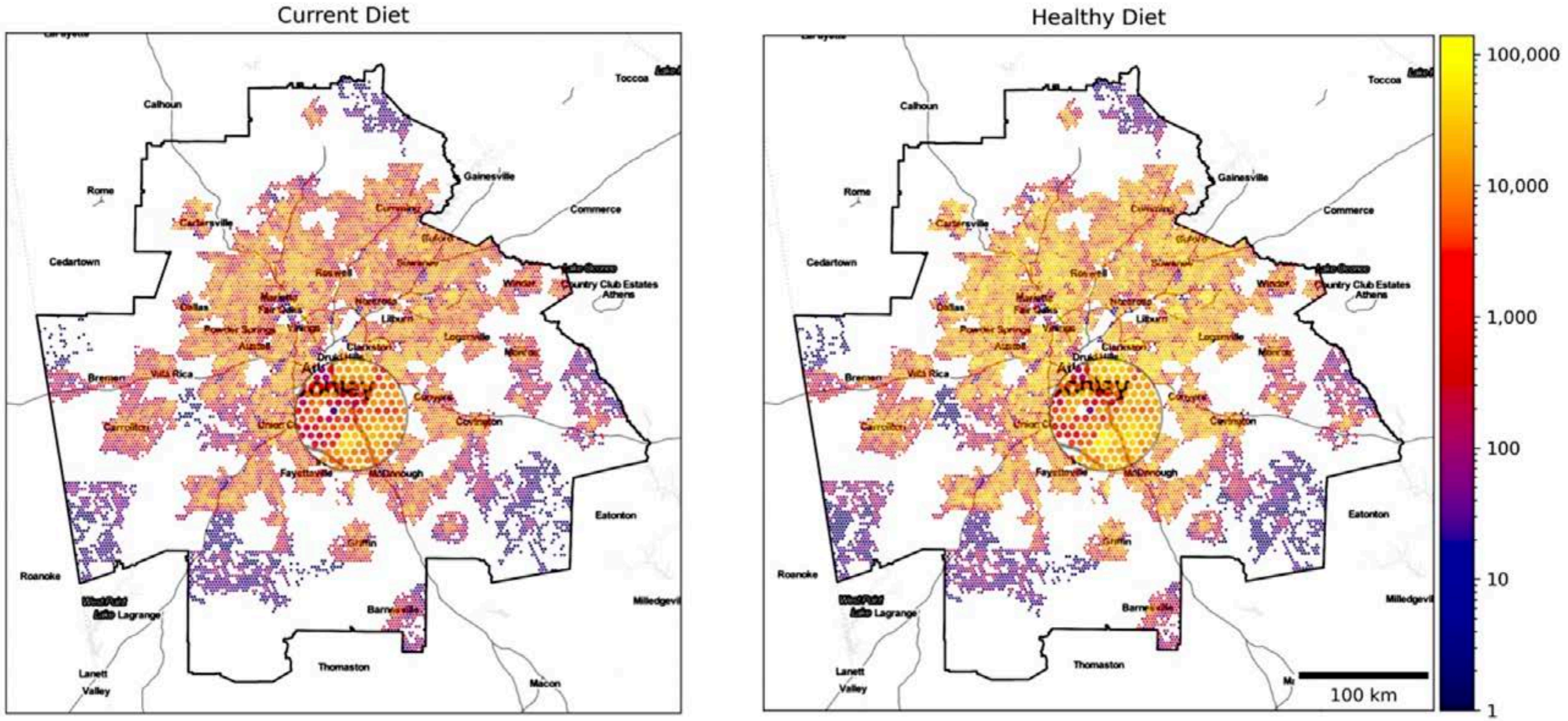
Food Availability Atlas Data for Atlanta; Population Without Access to a Grocery Store Within Walking Distance (~ ½ mile).

VF Production (kg/year) Needed to Supply Fresh Vegetables to Low-Access Communities in Atlanta

In 2019, ~1.9M people in Atlanta, GA had low access to a full-scale grocery store within 1 mile of home (~30% of the population of the Atlanta Metropolitan Statistical Area)

To meet this need:

- ~81M kg/year of vegetables would be produced by VF agriculture, occupying a land area of 1.2M m^2
- The VF farms would consume ~780 GWh/year, ~0.5% of the total per capita energy use for the low-access VF customers



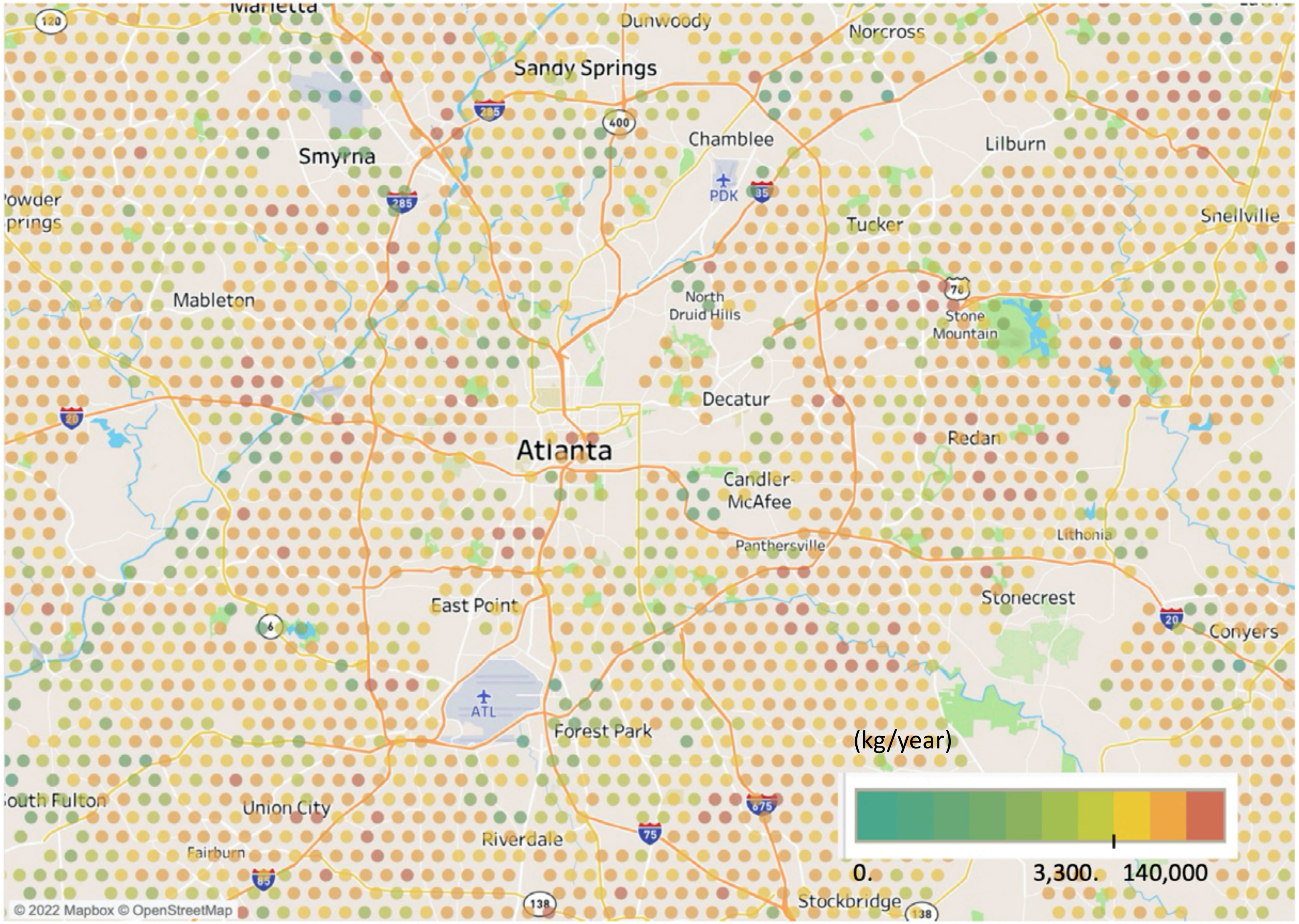
VF production (kg/year) needed to supply fresh vegetables to people with low-access to grocery stores in Atlanta, GA. Each dot represents the low-access population in 1 square km. Sources; USDA 2021b; census TIGER/Line, NREL analysis.

VFs can be Scaled to Serve Customers Within Walking Distance

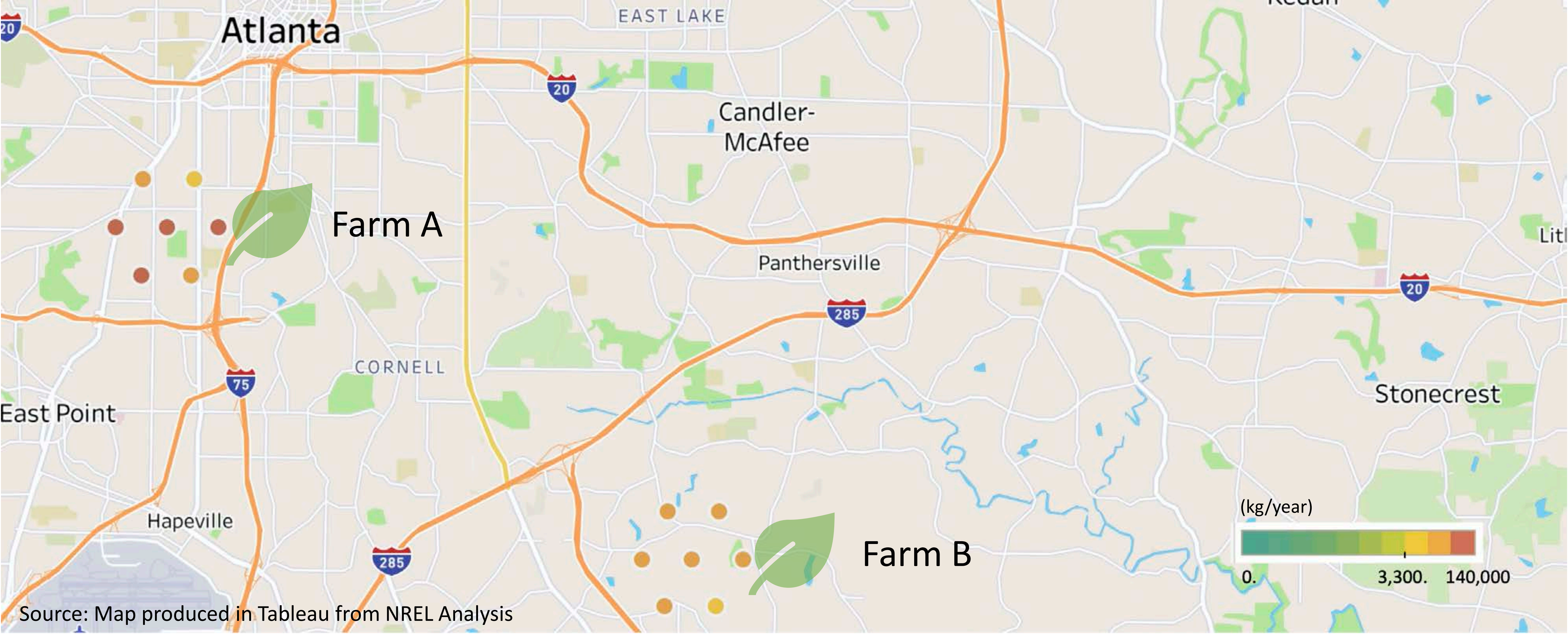
VF vegetable production needed for a healthy diet for people who currently live more than 1 mile from a grocery store (kg/year).

The color of each dot represents production for the low-access population within 1 square km.

The average size is about 3,300 kg/year, but some are up to 140,000 kg/year



Source: Map produced in Tableau from NREL Analysis



Source: Map produced in Tableau from NREL Analysis

Farm A: 261,000 kg vegetables/year

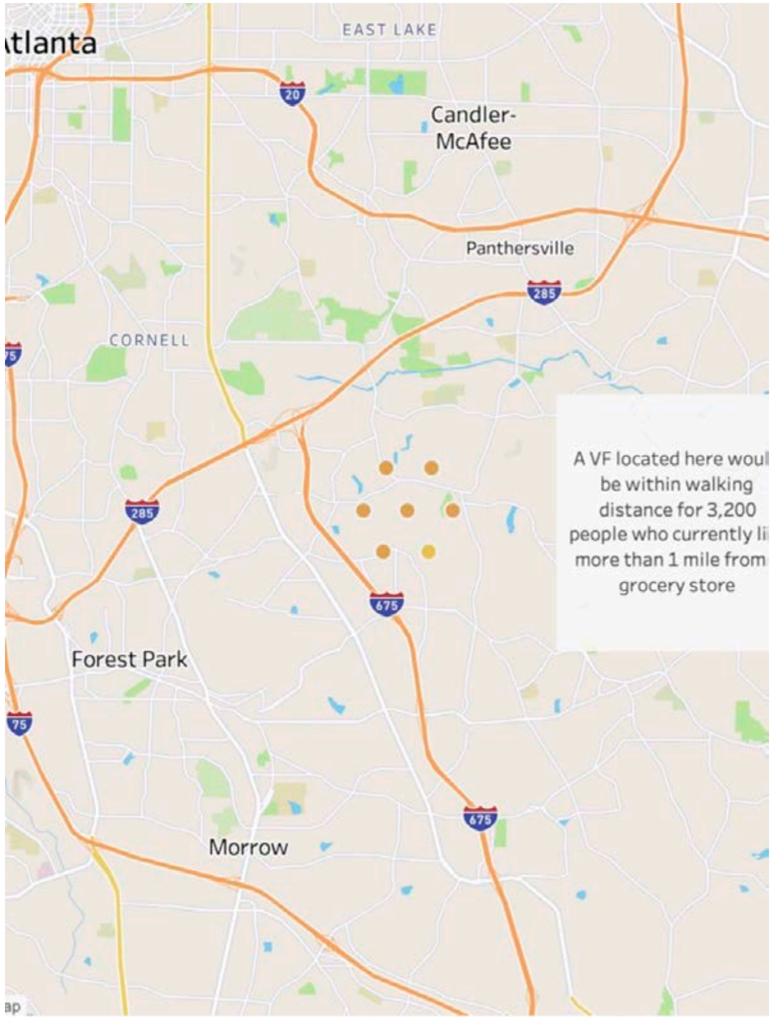
- Walking distance for 6,100 people currently with low-access
- 3,900 m2 (42,000 ft2) floorspace

Farm B: 138,000 kg vegetables/year

- Walking distance for 3,200 people currently with low-access
- 2,100 m2 (22,000 ft2) floorspace

Key Takeaways

- VFs can be implemented at almost any scale and could supply fresh vegetables for a healthy diet to currently underserved communities.
- VFs, have the potential to reduce water use for vegetable production by 50%, mitigating the water impacts of transitioning to a Healthy American Diet.
- VFs can be integrated into cities. VFs require only a fraction of the land area of in-ground farming and efficient lighting and heating, cooling and humidity control can reduce electricity use to values comparable to the current vegetable production supply chain.



Future Research

- Expand the VF analysis to include aquaculture and optimize integration of VFs with building (e.g., explore trade-offs with rooftop greenhouses).
- Develop a VF-building integration model to accurately predict the energy, water, and other impacts of integrating VFs with buildings.
- Investigate the feasibility of using brownfields, underutilized shopping malls, underutilized office buildings etc. for VFs in case study locations.
- Complete a national scale VF analysis.

Thank You

www.nrel.gov

NREL/PR-6A20-83178

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Advanced Manufacturing Office The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL Transforming ENERGY